ENDEAVOUR

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Volume XVIII Number 69

JANUARY 1959

ENDEAVOUR

The British quarterly scientific journal ENDEAVOUR was first published, by Imperial Chemical Industries Limited, in January 1942. Its purpose is to provide scientists, especially those overseas, with news of the progress of the sciences. While emphasis is laid upon British work, occasional articles from overseas contributors are included and impartial reference is made to the world's scientific literature. To make the journal truly international in character it is published in five separate editions—English, French, German, Italian, and Spanish.

No charge is made for ENDEAVOUR. It is distributed to senior scientists, scientific institutions, and libraries throughout the world, the guiding principle being that of helping scientists overseas to maintain those contacts which their British colleagues have always so much valued. Within these limits the Editors are at all times glad to consider the addition of new names to the mailing list.

The drawing on the cover is of the bark Endeavour, *which, commanded by Captain James Cook and carrying a number of scientific workers, was sent out by the British Admiralty in* 1768 *to chart the South Pacific Ocean and observe the transit of Venus*

ENDEAVOUR

A quarterly review designed to record the progress of the sciences in the service of mankind

VOLUME XVIII January 1959 NUMBER 69

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Termination of the International Geophysical Year

31st December 1958 marked the end of the period of concerted physical observation of the Earth and the Sun known as the International Geophysical Year. Four years of active planning were necessary before it started, and its observational phase has just been completed. This will be followed by several more years during which the observations will be collated, exchanged, published, analysed, interpreted, and discussed. The three phases of planning, observation, and data treatment have not, however, been separated so clearly as the above might suggest. Parts of the observational phase began before 1st July 1957, and some will continue after 31st December 1958: likewise the collection and discussion of the data began soon after the Year opened.

Over sixty nations have taken part in the project. Its growth to become by far the greatest international enterprise of co-operative scientific research ever undertaken astonished its initiators. Of the latter, the principal was Lloyd V. Berkner, who in 1950 proposed that in 1957–58 there should be a third International Polar Year, to succeed the first and second polar years of 1882–83 and 1932–33.

The organization has been marked by simplicity of method. There has been little protocol, and the central administration has been surprisingly small in staff and in cost, considering the magnitude of the enterprise. The national scientific academies have been its mainstay. It was they who appointed the committees that organized the national programmes in conformity with plans internationally devised. It was they who persuaded their own governments of the importance and value of these plans, and thereby gained the necessary authority and funds for their national participation. The academies aroused the interest and secured the valuable aid of the press, so that people throughout the world came to know of the International Geophysical Year.

As early as 1950 it was expected that 1957–58 would nearly coincide with a sunspot-maximum period. The solar activity during this period has, in fact, proved to be of an intensity unprecedented during the two centuries or more of reliable quantitative estimation. Consequently there have been many specially interesting solar flares, auroras, and magnetic and ionospheric storms affecting also cosmic rays. The detailed scientific results are far too numerous even to outline here.

Two particularly interesting features of the International Geophysical Year achievements are observations carried out in the Antarctic and the launching of earth satellites. Our knowledge of the great southern continent has leaped forward: its study will continue without a break, although in 1959 on a somewhat reduced scale. At the beginning of the International Geophysical Year the satellite part of the programme was a hope, indeed an expectation, but one not unmingled with doubt. The launching of the first Russian satellite on 4th October 1957 marked a new epoch in the history of our race. By the time of the last full meeting of the central organizing body in Moscow last August seven satellites had been launched, three by Russia and four by the United States. Already they have revealed important new results, though many of their data still remain to be studied and published. They have shown that the Earth's atmosphere extends further into space than had been thought, and that above a few hundred miles there is a layer, hitherto unsuspected, in which there are electrons of considerable energy, although much less than that of cosmic rays.

In a world suffering from serious political tensions the International Geophysical Year has been a unifying force. Participation has been open to the academies of all countries, without regard to the colour, race, religion, or mode of government of their people. Among the few notable—and much-regretted—gaps in participation only one has been due to political considerations.

The International Geophysical Year has also been a unifying force in the geophysical and solar sciences. Their international aspects have long been under the care of several international scientific unions—of geodesy and geophysics, of astronomy, of scientific radio, of pure and applied physics, of geography, and so on. The common interests of the unions have been watched over by the International Council of Scientific Unions (ICSU), composed of representatives of the unions and of the national scientific academies. The central organizing body of the International Geophysical Year (CSAGI) represents the International Council and the unions, and not the nations to which they belong. The central

organizing body has been assisted by an advisory council composed of one representative of each adhering nation or territory. There has in the past been much inter-union co-operation between scientists working in the different branches of geophysics and solar physics, but never before has this been so effective, intimate, and widespread as in the International Geophysical Year.

In executing their agreed shares in the enterprise the nations concerned have co-operated generously and freely. There has been no bargaining about their respective contributions: each nation has done what it could, at its own cost, and there have been many instances of mutual help. The same liberal principles govern the use of the observations made. The data obtained are to be available to scientists everywhere, regardless of whether their countries contributed much, little, or nothing at all.

The expenses of the central organization—for secretariat, meetings, publications, and so on—have been met from several sources. Initially the International Council of Scientific Unions was the sole provider. Then the United Nations Educational, Scientific and Cultural Organization became a generous supporter, both financially and in other ways. Later the participating committees gave generously to the CSAGI funds, on a free-will basis. Together with such gifts must be mentioned the devoted personal services of tens of thousands of scientists—and secretarial and other assistants—sometimes under hard conditions of tropical heat or polar cold or ocean storm. The International Geophysical Year has been served with enthusiastic loyalty and beyond common measure by men and women in all parts of the world. Among their motives have been a desire for knowledge and a sense of unity with all races of mankind in a peaceful enterprise for the benefit of all.

Such idealism, and a spirit of friendly emulation, have marked the approach to a multitude of International Geophysical Year problems. Those concerned have reviewed anew the complicated physical phenomena of our planet and the Sun. To help to study them they have devised many new instruments and kinds of apparatus for observation. They have planned the use of these devices on land and sea and in the air; this frequently involved complex tasks of organization. New institutions have been set up, such as centres for forecasting terrestrial disturbances energized by storms on the Sun, and World Data Centres in which the observations will be stored and from which they will be made universally available. One such centre is at Slough, England, for rocket and satellite data. To assist the organization of these data centres a special full-time officer, the Co-ordinator, was appointed in 1956; his branch of the central organization will close late this year, but the centres themselves will be continuing institutions. The solar terrestrial forecasting centre and the complex communications system associated with it have been the charge of one of the fourteen CSAGI Reporters, each of whom was responsible for one section of the plan.

Twelve of the Reporters have undertaken chief responsibility for planning the twelve different main sections of the programme—meteorology, geomagnetism, aurora and airglow, ionosphere, solar activity, cosmic rays, latitudes and longitudes, oceanography, glaciology, seismology, gravimetry, and nuclear radiation. One Reporter has acted similarly in regard to the rocket and satellite programme, which has concerned several of the twelve sections. The work of these Reporters will continue during the third phase of the project.

In August 1957 the CSAGI held a final meeting in Moscow to approve the plans for the third phase. Many of the observations already made were discussed and the plans for the collection, publication, and interpretation of the data were considered. At this meeting the Russian committee proposed an extension of the International Geophysical Year enterprise until the end of 1959. They pointed out that the expense of setting up many new stations for various kinds of observation had already been incurred, and that to maintain them for another year would materially add to the data at a relatively small cost, especially in the case of stations that had started late. The Russian committee won agreement in urging that ICSU should organize the continuation of the valuable new features of the International Geophysical Year organization after the main project is over. The CSAGI also approved the continuation of the International Geophysical Year programme, so far as is possible for the national committees, under the new name of International Geophysical Corporation 1959. Thus although the International Geophysical Year period of observation has ended, much of the programme and institutions will continue, at least for the present year, and the present and succeeding years will see the gradual threshing of the great harvest of knowledge so far gathered.

The transuranium elements

GLENN T. SEABORG

No transuranium elements were known twenty years ago, but today there are ten, all essentially synthetic elements, one of which has been prepared on a relatively large scale, and news of others seems imminent. The preparation and identification of these elements involves new bombardment techniques and new methods of analysis adapted to small quantities of short-lived elements. These techniques, and the results achieved by them, are discussed here by one who has for many years been most intimately concerned with this research.

The study of the transuranium elements is an exciting branch of science, which started less than twenty years ago and has a clearly discernible future of great expansion. These elements represent the realization of the alchemists' dream of transmutation. They have played an important role in the recent renaissance of inorganic chemistry. An advance as fundamental as a ten per cent increase in the number of chemical elements has, as one might anticipate, contributed much to our fund of the most basic scientific knowledge, especially in the fields of chemistry and physics.

The chemistry and physics of the longer-known transuranium elements are already remarkably developed, and extremely interesting. Neptunium has an isotope sufficiently long lived to be safe to handle with moderate precautions in ordinary laboratories; plutonium and curium have similarly long-lived isotopes which should eventually make these elements available for broader investigation throughout the world when they become more available. One of the transuranium elements, plutonium, is particularly interesting. It has an isotope with nuclear properties such that it is destined to play an extremely important role in the history of mankind. Plutonium was discovered and methods for its manufacture were worked out under the cloak of secrecy during the last war. It was the first synthetic element to be seen by man and the first example of large-scale production of an element by transmutation. Plutonium has most unusual chemical and metallurgical properties. For example, it has four oxidation states which may exist in aqueous solution in equilibrium with each other at appreciable concentrations. The metallic form has six allotropic modifications between room temperature and its melting point, some with properties unknown in any other metal. The alpha-radioactivity and physiological behaviour of its fissionable isotope, Pu^{239}, make this one of the most dangerous known poisons. The announcement of its discovery to the world was through the atomic bomb that fell on Nagasaki. Plutonium, of course, has an important future in nuclear power. The fissionable isotope Pu^{239} makes its source isotope U^{238}, which is not fissionable with slow neutrons, a potential nuclear fuel. The fertile U^{238} is 'burned' by going through the intermediate fissionable Pu^{239}.

The discovery of the first transuranium element followed a false start six years earlier. When Enrico Fermi and his co-workers first bombarded uranium with slow neutrons in 1934 they found that a number of artificially radioactive species were produced, and in the immediately following years many more such substances were observed. Most of these were thought to be transuranium elements. Chemical investigation, however, led to the discovery of the fission process rather than to the discovery of transuranium elements. Subsequent work has shown that practically all the radioactive species believed to be transuranium elements were in fact fission products of uranium. In 1940 E. M. McMillan and P. H. Abelson discovered the first transuranium element. This was neptunium, with atomic number 93. In the following years, many more transuranium elements, plutonium (94), americium (95), curium (96), berkelium (97), californium (98), einsteinium (99), fermium (100), mendelevium (101), and element 102 were synthesized and identified. The elements up to and including einsteinium have isotopes sufficiently long lived to be isolated in macroscopic, that is weighable, quantities, but this does not seem to be true beyond einsteinium.

The transuranium elements are, for all practical purposes, synthetic in origin and must be produced by transmutation, starting, in the first instance, with uranium. However, two of them, neptunium and plutonium, are present in trace concentrations in uranium ores as the result of the action of the neutrons which are present. Investigation

of these new elements has resulted in the contribution of much information to inorganic chemistry, since they have a rich and varied chemical behaviour, form unusual compounds, and in some cases display an extraordinary complexity in solution. The relationship of these elements to each other and to the other elements is now within our understanding. Problems inherent in the study of these elements, such as those of handling quantities of material so small as to be unweighable, of working in safety with radioactive materials, and of preparing and identifying elements of ever increasing atomic number, are being solved.

POSITION IN THE PERIODIC TABLE

Ideas on the position in the Periodic Table (Table 1) of the heaviest elements have varied considerably over the years. Until the last war, thorium, protoactinium, and uranium were commonly placed immediately below the elements hafnium, tantalum, and tungsten, which are members of a transition series in which the 5d electron shell is being filled. This placing was based on the assumption that the three heavy elements were members of a 6d electron transition series. The appearance of N. Bohr's paper on the quantized nuclear atom in 1913 led to suggestions that a 5f electron transition series should start in the region thorium to element 95 inclusive, before the completion of the 6d electron shell. With the discovery of neptunium and then plutonium, the boundaries of the Periodic Table were transcended, and as knowledge of the first transuranium elements accumulated, it became evident that a whole new family of elements, some known and some still to be discovered, existed in this region of the Periodic Table.

The fact that the transuranium elements are members of a transition series similar to the rare earth, or lanthanide, series is useful in predicting the chemical properties of these elements before they are actually detected. This particular pattern of similarity, recognized by the author in 1944 on the basis of the chemical properties of neptunium and plutonium, was the key to the discovery of elements 95 and 96 (americium and curium) and has been essential to the discovery of the transcurium elements. Since all the elements beyond actinium seem to belong to the actinide group (a name chosen by analogy with the lanthanide group), the elements thorium, protoactinium, and uranium have been removed from the positions they occupied in the Periodic Table before 1939 and placed in this transition family; as we shall see, elements 104, 105, and 106 will presumably take over the positions previously held by thorium, protoactinium, and uranium. Thus we have the interesting result that the newcomers have affected the face of the Periodic Table, and a change has been made after many

TABLE I

1 H 1·0080																	2 He 4·003
3 Li 6·940	4 Be 9·013											5 B 10·82	6 C 12·011	7 N 14·008	8 O 16·000	9 F 19·00	10 Ne 20·183
11 Na 22·991	12 Mg 24·32											13 Al 26·98	14 Si 28·09	15 P 30·975	16 S 32·066	17 Cl 35·457	18 A 39·944
19 K 39·100	20 Ca 40·08	21 Sc 44·96	22 Ti 47·90	23 V 50·95	24 Cr 52·01	25 Mn 54·94	26 Fe 55·85	27 Co 58·94	28 Ni 58·71	29 Cu 63·54	30 Zn 65·38	31 Ga 69·72	32 Ge 72·60	33 As 74·91	34 Se 78·96	35 Br 79·916	36 Kr 83·80
37 Rb 85·48	38 Sr 87·63	39 Y 88·92	40 Zr 91·22	41 Nb 92·91	42 Mo 95·95	43 Tc	44 Ru 101·1	45 Rh 102·91	46 Pd 106·4	47 Ag 107·880	48 Cd 112·41	49 In 114·82	50 Sn 118·70	51 Sb 121·76	52 Te 127·61	53 I 126·91	54 Xe 131·30
55 Cs 132·91	56 Ba 137·36	57 La See La series	72 Hf 178·50	73 Ta 180·95	74 W 183·86	75 Re 186·22	76 Os 190·2	77 Ir 192·2	78 Pt 195·09	79 Au 197·0	80 Hg 200·61	81 Tl 204·39	82 Pb 207·21	83 Bi 208·99	84 Po	85 At	86 Rn
87 Fr	88 Ra 226·03	89 Ac See Ac series	(104)	(105)	(106)	(107)	(108)										

Lanthanide series	57 La 138·92	58 Ce 140·13	59 Pr 140·92	60 Nd 144·27	61 Pm	62 Sm 150·35	63 Eu 152·0	64 Gd 157·26	65 Tb 158·93	66 Dy 162·51	67 Ho 164·94	68 Er 167·27	69 Tm 168·94	70 Yb 173·04	71 Lu 174·99
Actinide series	89 Ac 227·04	90 Th 232·05	91 Pa 231·05	92 U 238·04	93 Np 237·06	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 E	100 Fm	101 Mv	102	(103)

years during which it seemed to have assumed its final form.

NEPTUNIUM

The discovery of the first transuranium element, neptunium, resulted from McMillan's investigation of the fission process. In measuring the energies of the two main fragments from the neutron-induced fission of uranium, he found that there was another radioactive product of the reaction, one which did not recoil sufficiently to escape from the thin layer of uranium undergoing fission. He suspected that this was a product formed by neutron capture in the uranium. McMillan and Abelson were able to show on the basis of their chemical work that this product was an isotope of element 93 (Np^{239}), arising by beta decay of U^{239} formed by neutron capture in U^{238}.

It was not obvious what the electronic configuration and chemical properties of neptunium might be. Uranium was known to have some similarity to tungsten, and it was thought that element 93 might resemble rhenium, the next element beyond tungsten. There was the possibility, however, that neptunium might be a member of some new type of transition series among the heavy elements. McMillan and Abelson's investigation of neptunium showed that it resembles uranium, not rhenium, in its chemical properties. This was the first definite evidence that the 5f electron shell is filled in the transuranium region.

The early investigation of neptunium, as of all the transuranium elements, was made by the tracer technique. In this method, an element having chemical properties similar to those of the element being studied is used to follow the behaviour of the radioactive element, which is present in amounts as small as 10^{-10} g, or even less. The element is followed in the various reactions by means of its radioactivity rather than by chemical analysis. In spite of the smallness of the quantities present, much can be deduced about the chemical properties of an element—for example, the solubility of its compounds, its oxidation-reduction potentials, and its formation of complex ions—by the use of such methods.

PLUTONIUM

Plutonium was next to be discovered. By bombarding uranium with deuterons, E. M. McMillan, J. W. Kennedy, A. C. Wahl, and the author, in late 1940, succeeded in preparing a new isotope of neptunium, Np^{238}, which decayed to Pu^{238}. The half-life of this isotope was found to be sufficiently long to permit detection and to make possible our obtaining considerable chemical information about it by tracer studies. Armed with this information about the new elements, J. W. Kennedy, E. Segrè, A. C. Wahl, and the author in 1941 identified the most important plutonium isotope, Pu^{239}, as the decay product of Np^{239} and we were able to prove that Pu^{239} undergoes fission with slow neutrons.

The realization that plutonium, as Pu^{239}, could serve as a nuclear weapon and that it might be created in quantity in a nuclear chain reactor made it imperative to carry out chemical investigations of plutonium with microgram quantities. In August 1942, B. B. Cunningham and L. B. Werner succeeded in isolating about a microgram of Pu^{239} which had been prepared by cyclotron irradiations. Thus plutonium was the first man-made element to be obtained in visible quantity.

A background of manipulative techniques for this ultramicrochemical work was provided by the pioneer investigations of P. L. Kirk and A. A. Benedetti-Pichler. If extremely small volumes are used, even microgram quantities of material can give relatively high concentrations in solution, and with the development of balances of the required sensitivity, micrograms were also sufficient for gravimetric analysis. Liquid volumes in the range 10^{-1} to 10^{-5} ml were measured with an error of less than one per cent by means of finely calibrated capillary tubing, the movement of liquid being controlled by air pressure. Smaller pipettes were constructed to fill by capillary action. Chemical glassware, such as test tubes and beakers, was constructed from capillary tubing having an internal diameter of 0·1–1 mm and was handled with micromanipulators. The weights of solid reagents and precipitates handled in ultra-microchemical work are usually in the range of 0·1–100 μg. There are some changes in method involved in the change of scale—thus, solids are usually separated from liquids by centrifuging rather than by filtration. The actual chemical work is usually done on the mechanical stage of a microscope, where the essential apparatus is within view (figure 2). Among the early accomplishments in ultramicrochemistry were the isolation of pure neptunium (figure 3) and pure plutonium compounds (figure 4) as well as the preparation of plutonium metal. Figures 1 and 5 show schematic drawings of the experimental arrangements used in the preparation of pure plutonium metal and pure plutonium trichloride.

Plutonium is the only synthetic element that has

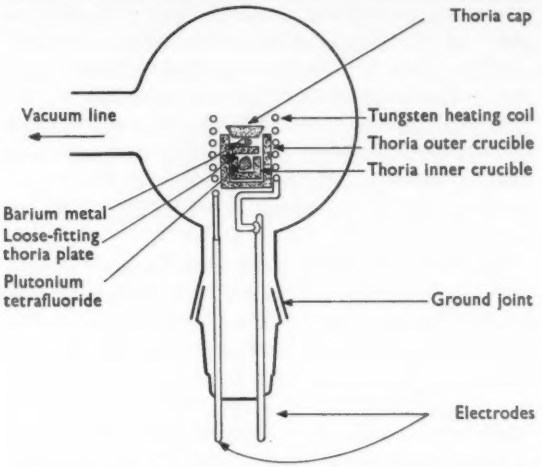


FIGURE 1 – *Apparatus used in the first preparation of plutonium metal (November 1943). 35 μg of plutonium tetrafluoride was treated with volatilized barium metal in a thoria crucible at 1400° C. The metallic plutonium was produced as silvery globules weighing about 3 μg each.*

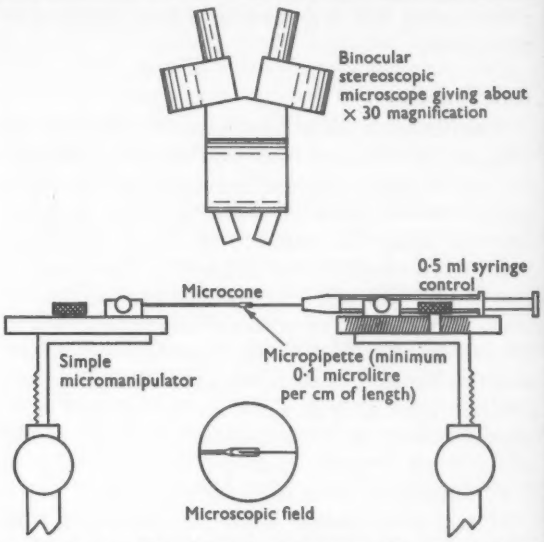

Binocular stereoscopic microscope giving about × 30 magnification
0·5 ml syringe control
Microcone
Simple micromanipulator
Micropipette (minimum 0·1 microlitre per cm of length)
Microscopic field

FIGURE 2 – *Experimental arrangement for the study of precipitation reactions on the microgram scale.*

been produced and isolated in kilogram quantities. The large plant at Hanford, Washington, was constructed on the basis of investigations performed with about 2 mg of plutonium; the scale-up between ultramicrochemical experiments to the final Hanford plant corresponds to a factor of about 10^9, surely a scale-up of unique proportions.

Frequently chemical investigation of plutonium and of other transuranium elements is carried out on a scale of a milligram or less by choice, rather from any limitation on supply—Pu^{239} is exceedingly toxic because of its high alpha-radioactivity, amounting to about 140 000 000 alpha-disintegrations per minute per milligram; special equipment and precautions, as well as the use of material in very small amounts, are necessary when working with it.

AMERICIUM AND CURIUM

After plutonium had been produced in quantity, the discoveries of americium (1944–5) and curium (1944) were made. The speed of discovery of these elements was due largely to the accurate prediction of their chemical properties on the basis of their assumed position in the Periodic Table (page 6). Curium, discovered by R. A. James, L. O. Morgan, A. Ghiorso, and the author, was synthesized as Cm^{242} by the bombardment of plutonium with helium ions. The production of americium by James, Ghiorso, and the author was accomplished by preparing Pu^{241}, which decays by beta emission to Am^{241}.

IDENTIFICATION BY ION EXCHANGE

The ion-exchange technique, coupled with element-by-element comparison of the behaviour of corresponding actinide and lanthanide elements, has been essential in the discovery of the transuranium elements. Since the actinide elements above plutonium are predominantly trivalent in solution and have a close chemical resemblance, most conventional chemical separations are not suitable. Again, the first isotopes of the new actinide elements were obtained in very small amounts, and are very short-lived. Specific and rapid methods are therefore necessary in identifying these elements, and ion exchange provides both. Much of the chemical knowledge we have of the actinide elements heavier than curium is concerned with their ion-exchange and elution properties.

The trivalent actinide and lanthanide ions in aqueous solution undergo a cation exchange when a solid organic base-exchange polymer is stirred in. The solid material can then be placed at the top of a glass column filled with more of the organic polymer that is free of the actinides or lanthanides. Elution can then be accomplished by pouring through the column a solution containing ions that form complex ions with the actinide or lanthanide ions. In certain well-behaved systems the lanthanide elements elute from the column in the inverse order of their atomic numbers, that is, lutetium can be collected as the first element in the drops coming through the column, ytterbium

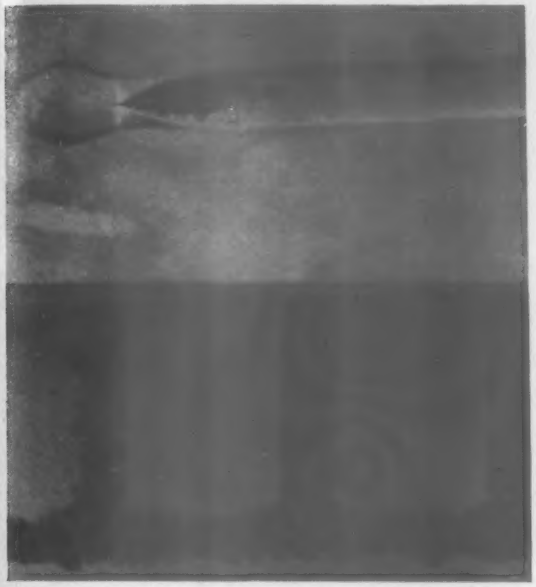


FIGURE 3 – *First neptunium compound isolated. The neptunium, present as the oxide, appears at the bottom of the capillary tube. The sample was isolated in* 1944 *and weighed about* 10 μg. *Below the sample, for purposes of comparison, is a millimetre scale.*

FIGURE 4 – ***First plutonium compound to be weighed*** (10*th September* 1942). *The plutonium, present as the oxide, appears as a crusty deposit, indicated by the arrow, near the end of a platinum weighing boat which is held by forceps. The weight of the plutonium oxide was* 2·77 μg. (×20)

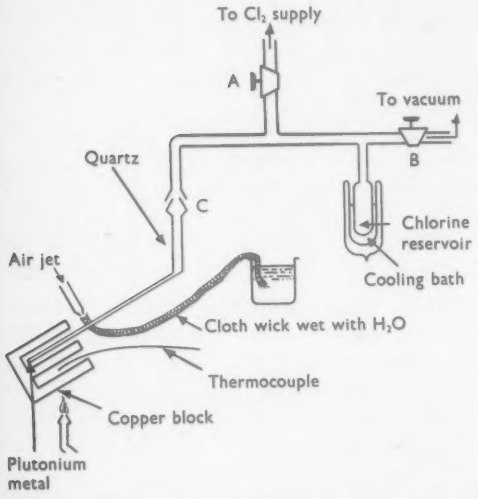


FIGURE 5 – *Apparatus used in the first preparation of* $PuCl_3$ (*February* 1944). *The compound was prepared by treating a* 50 μg *piece of plutonium metal with chlorine gas. After placing the plutonium in the capillary tube, the system was evacuated. Chlorine gas was added, and a small amount condensed in a reservoir as shown. The system was closed and remained filled with chlorine at a pressure of about* 60 *mm Hg. The copper block was heated to* 45° *C, and the reaction product was formed in the top of the capillary tube. The section of the capillary containing the product was sealed off and the compound formed was identified by X-ray diffraction.*

as the second element, and so on to cerium. The whole process bears a close resemblance to chromatography. In the case of the actinides, the undiscovered element 103 will leave the column first, followed by element 102, and so on down the scale of atomic numbers.

BERKELIUM AND CALIFORNIUM

At the end of 1949 and beginning of 1950, experiments led to the production of elements 97 and 98, berkelium and californium. The first six transuranium elements were discovered almost in pairs, with time lapses corresponding to necessary improvements in technique and the accumulation of starting material. Milligram amounts of americium for target material were prepared by the intense neutron irradiation of plutonium for a long time; this process builds up the heavier elements by a series of neutron captures. Curium for target material was prepared in microgram amounts by the neutron irradiation of some of the americium. Both of these neutron bombardments were carried out in high-flux reactors. Berkelium, as the isotope Bk^{243}, was discovered by S. G. Thompson, A. Ghiorso, and the author in December 1949, as a result of the bombardment of americium with helium ions. Californium was first synthesized and identified by S. G. Thompson, K. Street Jr, A.

Ghiorso, and the author in February 1950, the isotope Cf^{245} being produced by the bombardment of microgram amounts of curium with helium ions. The identification of californium was accomplished with a total of about 5000 atoms.

EINSTEINIUM AND FERMIUM

The first test thermonuclear explosion, which took place in the Pacific in November 1952, led to the discovery of elements 99 and 100, einsteinium and fermium. These two elements were found in debris, collected first on filter papers attached to aeroplanes which flew through the explosion area and later in more substantial quantities by gathering up surface materials from a neighbouring atoll. The uranium in the fission-fusion device was subjected to an instantaneous intense neutron flux which gave rise to very heavy uranium isotopes. These rapidly decayed into heavy isotopes of plutonium, americium, curium, berkelium, californium, and elements 99 and 100. These reaction products were investigated by groups at the University of California Radiation Laboratory, Argonne National Laboratory, and Los Alamos Scientific Laboratory. The two elements were discovered by Ghiorso and co-workers at the three laboratories.

Einsteinium and fermium can be synthesized by a number of methods. Chief among these is the irradiation of plutonium for several years with an extremely high neutron flux in such a reactor as the Materials Testing Reactor at Arco, Idaho. The einsteinium used to produce element 101 was prepared in the Materials Testing Reactor.

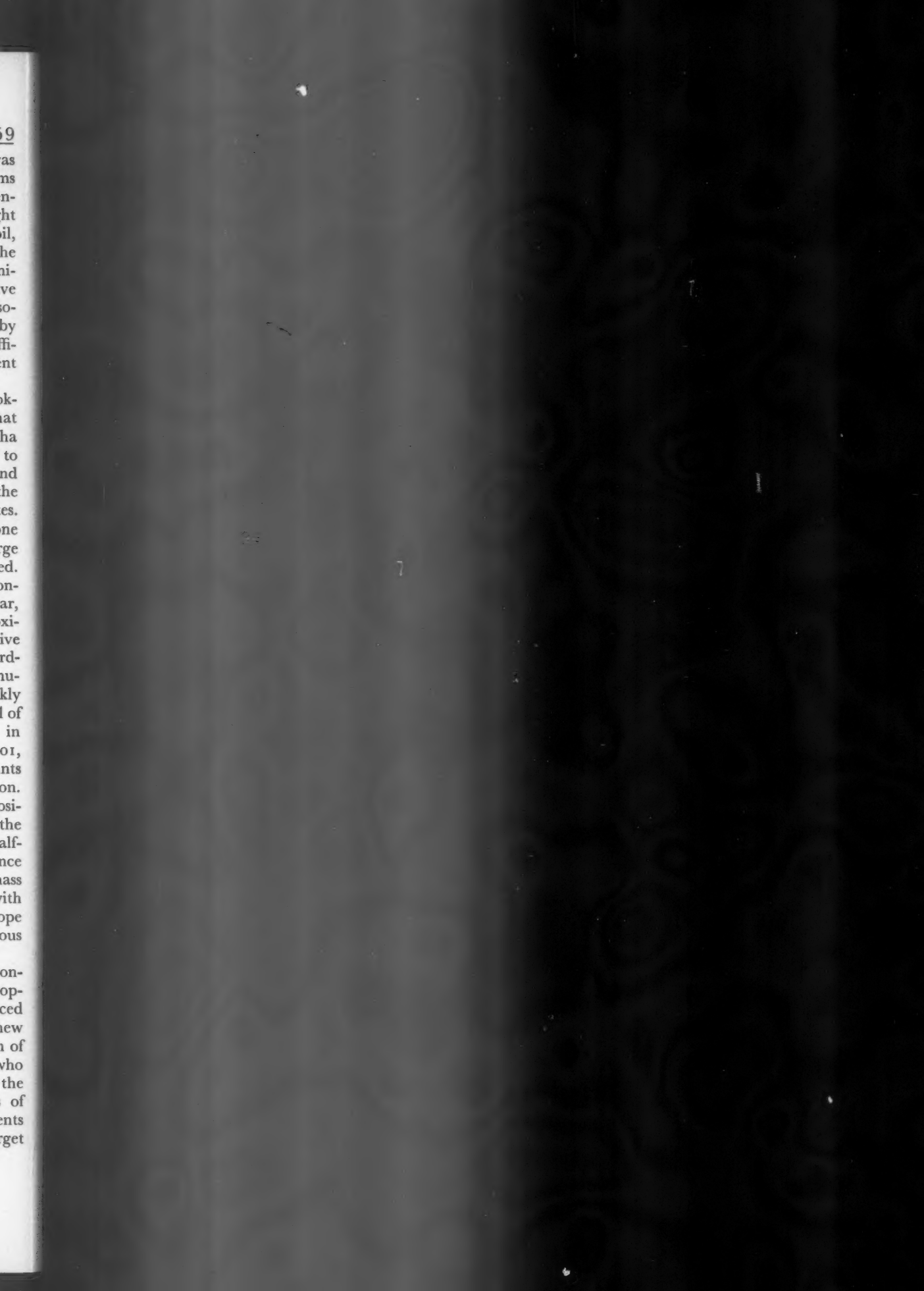
MENDELEVIUM

The synthesis of element 101 was planned and accomplished not only with an amount of target einsteinium (E^{253}) so small as to be unweighable, but also with the expectation that no more than one atom of element 101 per experiment would be produced. Only about one thousand million atoms of E^{253} were available for target material. In addition, the separation of the one atom of element 101 from the 10^9 atoms of target einsteinium and its ultimate complete chemical identification by separation in the eka-thulium position by the ion-exchange method would have to be accomplished. These requirements necessitated new techniques, and also some luck; fortunately, both were forthcoming. The new technique involved the separation of element 101 from the einsteinium in the target by the recoil method. The einsteinium was plated on to a gold foil in an invisibly thin layer. The helium-ion beam was sent through the back of the foil so that the atoms of element 101, recoiling because of the momentum of the impinging helium ions, could be caught on a second thin gold foil. This second gold foil, containing recoil atoms, yet relatively free of the target einsteinium, was dissolved and the chemical separations were performed. Very sensitive methods were available for the detection of isotopes decaying by alpha-particle emission or by spontaneous fission. These methods were so efficient that as little as one or two atoms of element 101 per experiment could be detected.

The earliest experiments were confined to looking for short-lived alpha-emitting isotopes that might be due to element 101. However, no alpha activity was observed that could be attributed to element 101, even when the time between the end of the bombardment and the beginning of the alpha-particle analysis was reduced to five minutes.

The experiments were continued, and in one of the subsequent bombardments, a single large pulse due to spontaneous fission was observed. Chemical experiments indicated that the spontaneous fission counts, when they did appear, came in chemical fractions corresponding approximately to element 100 or 101. In the definitive experiments, three successive three-hour bombardments were made, and, in turn, their transmutation products were completely and quickly separated by the ion-exchange method. A total of five spontaneous fission counts was observed in the elution position corresponding to element 101, while a total of eight spontaneous fission counts was also observed in the element 100 position. No such counts were observed in any other position. The spontaneous fission activity in both the element 101 and 100 fractions decayed with a half-life of about three hours. This and other evidence led to the view that the isotope has the mass number 256 and decays by electron capture, with a half-life of the order of an hour, to the isotope Fm^{256} which is responsible for the spontaneous fission decay.

On the basis of this evidence, the group, consisting of A. Ghiorso, B. G. Harvey, G. R. Choppin, S. G. Thompson, and the author announced the discovery of element 101. We gave the new element the name mendelevium in recognition of the pioneering role of Dmitri Mendeleev, who was the first to use the periodic system of the elements to predict the chemical properties of undiscovered elements. Subsequent experiments using larger amounts of einsteinium in the target



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have led to the production of over one hundred atoms of mendelevium. The indications are that mendelevium is a typical tripositive actinide element and a true eka-thulium, as expected.

ELEMENT 102

The discovery of element 102 was announced in 1957 as the result of work done at the Nobel Institute for Physics in Stockholm by a team of scientists from the Argonne National Laboratory, the Atomic Energy Research Establishment at Harwell, and the Nobel Institute. An isotope of the element was reportedly produced by bombarding Cm^{244} with cyclotron-produced $C^{13(+4)}$ ions and decayed with a half-life of about ten minutes by the emission of 8·5 MeV alpha particles. The name nobelium for element 102 was suggested by this group. Unfortunately it has not been possible to confirm this discovery in experiments performed at the University of California Radiation Laboratory. In April 1958 a group consisting of Ghiorso, T. Sikkeland, J. R. Walton, and the author at the Radiation Laboratory identified the isotope 102^{254} as a product of the bombardment of Cm^{246} with C^{12} ions accelerated in the new heavy-ion linear accelerator there. (The reaction is $Cm^{246}(C^{12}, 4n)$ 102^{254}). The element 102 isotope decays by alpha-particle emission with a half-life of about 3 seconds. It was detected by the chemical identification of its known daughter Fm^{250}, the atoms of the daughter element being separated from the parent element 102 by taking advantage of the recoil due to element 102 alpha-decay. Although the name nobelium for element 102 will undoubtedly have to be changed, the investigators have not, at the time of writing, made their suggestion for the new name.

COMPARISON OF ACTINIDES AND LANTHANIDES

The resemblance between the actinide and lanthanide elements suggests that their electronic structures must be similar. In the lanthanide elements, the fourteen 4f electrons are added one by one, beginning with cerium (atomic number 58) and ending with lutetium (atomic number 71). In the actinide elements, fourteen 5f electrons are added, beginning formally with thorium and ending with element 103. The evidence for this, which is too complex and lengthy to discuss in this article, lies in the chemical properties, absorption and fluorescence spectra in aqueous solution and crystals, crystallographic structure data, magnetic data, and spectroscopic data. The lanthanide gadolinium, with seven 4f electrons, and the actinide curium, with seven 5f electrons, are of especial interest because of the enhanced stability of the half-filled f-electron shell configuration. The two elements have been found to have properties that are strikingly similar. The family relationship within the actinide group means that the study of any one of them often gives indirect information about the chemical properties of another. Thus certain anomalous elution sequences among the transplutonium elements have made it possible to make deductions about the chemical properties of plutonium in relation to its electronic structure.

There are important differences between the actinide and lanthanide elements, however, due largely to the lower binding energies and less effective shielding by outer electrons of 5f (as compared to 4f) electrons. It appears that the first 5f electron is not present in thorium. Evidence to date indicates that uranium possesses three 5f electrons. The additional 5f electrons apparently are added to the succeeding elements in a regular fashion, proceeding through curium with its half-filled shell to the as yet undiscovered element 103 which presumably will have fourteen 5f electrons. In the early members of the actinide group particularly, the lower binding energies of the 5f electrons compared to the 4f electrons tend to make higher oxidation states more accessible. For these lighter actinide elements, the problem of assignment of electrons to 5f or 6d orbitals is difficult, since here the energy separations apparently lie within the range of chemical binding energies. It may not be possible to establish from the configuration of the gaseous atom the electronic structure of the compounds or of hydrated ions in aqueous solution. In the case of the lanthanide elements, the configuration of the gaseous atom includes, in general, only two electrons (beyond the xenon structure) outside the 4f shell, although the predominant oxidation state in aqueous solution is the trivalent state. It may also be noted that for a given element in the actinide group there is a stabilization of 5f compared to 6d electrons with increasing oxidation state.

However, the differences between the actinide and lanthanide groups give opportunities for the investigation of important new chemical phenomena. For example, their energetic position and larger spatial extension make the 5f orbitals available in bond hybridization; this leads to some very interesting complex ions. Similarly, the exposure of the 5f electrons can lead to field-splitting effects which can affect ionic entropies in

manners which have not been observed in the lighter elements.

FUTURE DEVELOPMENTS

The discovery of further new transuranium elements seems possible. Studies of the known isotopes of the transuranium elements have made possible the prediction of the decay properties of new isotopes. For decay by both alpha-particle emission and spontaneous fission, the regularities have been found to be greatest for nuclei which contain an even number of neutrons and an even number of protons, thus making predictions of the properties for undiscovered isotopes of this type more certain. The rates of decay by alpha-particle emission and by spontaneous fission are slower for isotopes having an odd number of protons or an odd number of neutrons or an odd number of both protons and neutrons. Unfortunately for the prospect of producing ever higher elements, the predictions suggest shorter half-lives as atomic number increases. By the time elements 104 and 105 are reached, we shall probably find that the longest-lived isotopes that can be made will exist barely long enough for chemical identification. In the case of element 104, the predicted half-lives of the longest-lived isotopes are measured in seconds or minutes and for element 105 in seconds. It should be mentioned, however, that any of these nuclides can have a specially hindered decay, leading to longer half-lives than those predicted. It is likely that the present basic criterion for the discovery of a new element, namely chemical identification and separation from all previously known elements, will have to be changed at some point. Careful measurements of decay properties and production yields and mechanisms, and the clever use of recoil techniques, should eventually allow the extension of effective identification to another half-dozen elements or so beyond the heaviest now known. In fact the identification of the first isotopes of all the new elements that will be discovered in the future probably will be accomplished through the use of such methods, and the production of isotopes with sufficiently long half-lives to allow chemical identification will follow later. For the isotopes with very short half-lives, some chemical identification can probably be made using simpler and faster methods involving migration, volatility, reactions with surfaces, or gas-flow reactions.

Some interesting predictions concerning superheavy nuclei have been made. J. A. Wheeler has been able to show that extra-nuclear electrons for atoms with atomic number substantially higher than 137 (often considered the upper limit) would behave normally because of the finite extension of the nucleus. Accordingly it would appear that there is no limitation on the existence of such heavy elements from the standpoint of the electronic structure of such atoms. The production of such nuclei would require extremely high neutron fluxes, of the order of 10^{31} neutrons per square centimetre per second, such as may be present in stars. It is difficult to see how such nuclei can be made on earth. There is no indication that such superheavy nuclei can be produced and detected, because the rate of decay increases rapidly as the atomic number increases. Unless unexpected islands of stability due to closed neutron or proton shells are found, predictions based on regularities in decay properties suggest that it should not be possible to produce and detect elements beyond another half-dozen or so.

The prediction of the chemical properties of elements beyond mendelevium seems to be quite straightforward. Element 103 should complete the actinide series, and it is expected that elements 104, 105, 106, etc., will be fitted into the Periodic Table under hafnium, tantalum, tungsten, etc. The filling of the 6d electronic shell should be followed by the addition of electrons to the 7p shell, with the attainment of the rare gas structure at hypothetical element 118. It seems quite certain that the chemical identification of elements 102 and 103 will eventually be made by ion exchange, using knowledge of their homologues ytterbium and lutetium and other actinide elements. Element 102 might be expected to have a stable trivalent oxidation state and a somewhat unstable bivalent state which may be of importance in the chemical identification of the element. The bivalent state of element 102, if it is comparable in stability to the bivalent state of ytterbium, may permit a rapid separation of element 102 from the other actinide elements by electrolytic or amalgam reduction using ytterbium as a carrier. The stability of the bivalent state may be reflected in the properties of the metallic state of the element, resulting in an unusually low density and a relatively high volatility. Element 103 might be expected to have only a trivalent oxidation state. Element 104 should be exclusively tetravalent in aqueous solution and should resemble its homologue hafnium. Element 105 should resemble niobium and tantalum, and to some extent protoactinium, with the pentavalent oxidation state expected to be the most important.

The chemical properties of element 106 can be predicted from those of tungsten, molybdenum, and to some extent chromium; thus we might expect to find the III, IV, V, and VI oxidation states. Elements 107, 108, 109, 110, etc., would be expected to have chemical resemblance to rhenium, osmium, iridium, and platinum respectively.

The possibility of preparing transfermium elements by the process of multiple neutron capture as a result of intense neutron bombardment over long periods of time is almost precluded by the fact that some of the intermediate isotopes have half-lives so short as to prohibit their presence in such appreciable concentrations as are required. Fortunately, there is another type of nuclear reaction that offers promise for the production of elements of higher atomic number than those now known. This is the method of bombardment with heavy ions. Reactions of this type have already been observed in many laboratories; isotopes of californium, einsteinium, and fermium have been produced by the bombardment of uranium with carbon ions, nitrogen ions, and oxygen ions, respectively. These ions can be accelerated in conventional cyclotrons. A linear accelerator capable of producing substantial beams of all the heavy ions up to neon and, possibly, usable beams of ions as heavy as those of argon has been constructed at the University of California at Berkeley. A similar accelerator is in operation at Yale University. Russia has shown a great interest in heavy ions and their application to the synthesis of transuranium elements and has accelerators for heavy ions under construction. Even with use of heavy ions, however, the source of target materials will present serious problems. New, expensive, high-flux reactors, producing 10^{15} to 10^{16} neutrons per square centimetre per second are needed in order to prepare even milligram amounts of berkelium, californium, and einsteinium within a reasonable space of time.

This short article has, of necessity, omitted even reference to many of the important aspects of the transuranium element field. In particular, it has not been possible to capture the international flavour of the work which has gone on in recent years. The emphasis has been on the chemical properties, the historical aspects, and the possibilities for future advances in this field. Much of interest could be told of the methods of production and of the many new long-lived isotopes which are becoming available in weighable amounts. The nuclear properties, which were barely mentioned, are of great interest. Over 80 isotopes of the transuranium elements are now known. The decay properties of these have been of great importance for the development of the Copenhagen school's unified model of the nucleus, and the induced and spontaneous fission properties of such isotopes are very important to the future development of a satisfactory theory for the nuclear fission process.

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Doppler and the Doppler effect

E. N. DA C. ANDRADE

The Doppler effect is today applied in themes ranging from aerial navigation to the expanding universe. This article describes the origin of the principle, which was first put forward with astronomical application in view, its history and present employment.

Doppler is a name known today in one connection only, that of the Doppler effect. In the case of certain other men of science, notably Hooke and Boyle, the laws that bear their name represent but a very small part of their achievement: Doppler, however, although a very diligent worker, contributed nothing else to science that is remembered or deserves to be remembered, if we except possibly an early paper on the stroboscopic effect. Today his effect, or principle, has very wide and important applications, to which reference will be made later, but, although his account of it was published in 1843[1], the full significance was slow to be realized. For instance, it was not held to be of sufficient importance to be mentioned in the well-known history of physics published by Heller in 1882–84.

Christian Doppler, the son of a master stonemason, was born in Salzburg on 29th November 1805. He had apparently some talent as a carver, but was not of sufficiently strong build to follow his father's craft. The mathematician Stampfer recognized the lad's ability, and as a result he was sent to study at the Polytechnic Institute in Vienna. Later he taught mathematics in a subordinate position, and, failing to get a good post, was in 1835 on the point of emigrating to America when he was appointed professor of mathematics at the *Realschule* in Prague. Later he went to the Prague Technical College as professor of 'elementary mathematics and practical geometry'; and it was while holding this post that he published his famous principle. His next position was as professor of mathematics, physics, and mechanics at the Mining Academy at Schemnitz. About this time he was beginning to be recognized as a man of distinction and was given an honorary doctorate by the University of Prague. A little later he went back to Vienna and in 1850 was made professor of experimental physics at the university there, which was the goal of his ambitions. His institute was the first to be founded in Austria for the study of physics. He did not long enjoy the position, however, for he died of lung trouble in 1853. It will be seen that he had a very varied career as a teacher and only towards the end of his life obtained an office of academic distinction.

He was, it appears, a man of upright and attractive character. On the hundredth anniversary of his birth, when his principle had proved its importance, he was awarded various posthumous honours in Salzburg, Prague, and Vienna, even having streets named after him in the two latter cities. In 1901 a bust of him was set up in the University of Vienna (figure 1). On what records of his appearance it was founded is unknown to the writer.

The paper in which Doppler established the principle by which his name lives appeared in the *Abhandlungen der Königlichen Böhmischen Gesellschaft der Wissenschaften* (Proceedings of the Royal Bohemian Society of Learning) in 1843, under the title *Ueber das farbige Licht der Doppelsterne* (On the coloured light of the double stars) [1]. The subtitle says that it is an attempt at a theory which includes Bradley's theorem of aberration. The main object is, then, to deal with the way in which the velocity of a moving source of light should affect the frequency as perceived by an observer: in fact Doppler states explicitly towards the end of his discussion that the purpose of the paper was to demonstrate not the possibility, but the necessity, of an influence of the very high velocities of the heavenly bodies on the colour and intensity of their light as observed by us.

Doppler begins by speaking of the triumphs of the transverse wave theory of light, referring to the fact—somewhat surprising to us—that at the time, 1842, there were still physicists who were not convinced of its validity. Colour depends on the frequency of the pulsations stimulating the eye, and anything that changes the interval between successive impulses changes the colour perceived. As long as source and observer are at rest the frequency observed is the frequency of the light emitted by the source, but if the observer is moving

[1] Almost invariably quoted as 1842. The paper was read on 25th May 1842 but was not published until 1843.

towards the source the frequency must increase, and if he is moving away from it, decrease. There must be similar effects if the source moves. Doppler says that at first hearing this may seem a purely academic distinction but that the honoured reader of what follows shall decide for himself. Whenever the velocity of source or observer is appreciable compared with that of the wave motion in its medium the effect is significant. Throughout he assumes that the waves (light waves in particular) are travelling in a medium through which the source and observer move freely, for which reason he refers more than once to Bradley's aberration. He uses, for instance, as an analogy a ship moving to meet or to retreat from a train of ocean waves.

He then considers the simple mathematical theory of the phenomenon and deduces, in a rather clumsy form, the equivalent of

$$n' = n\frac{c-u}{c-v}$$

where n is the frequency of the source, n' the frequency as appreciated by the observer, and c, u, and v are respectively the velocity of the wave in a stationary medium and the velocities of observer and source with respect to this medium, velocities being taken as positive when in the direction in which the wave is travelling.

FIGURE 1 – *Bust of Doppler.*

This formula can be simply derived by considering that the wavelength λ in the medium must be $(c-v)/n$, since the number of waves in a length c of the stationary medium is in a length $c-v$ when the source is moving in the direction of travel of the wave. The number n' of waves passing the observer per second is $(c-u)/\lambda$, since u/λ represents the number which do not reach the observer owing to his motion. Hence

$$n' = \frac{c-u}{\lambda} = n\frac{c-u}{c-v}$$

If u and v are small compared to c the magnitude of the effect depends only on the relative velocity of source and observer, and not on which of them moves relatively to the medium, since, if x is small, $1-x = 1/(1+x)$ approximately. If, however, u and/or v are large compared to c it makes a considerable difference, as can easily be seen by contemplating the case where u or $v = c$. If the source is moving in the direction of the wave motion, $n' = \infty$; if the source is moving in the opposite direction, $n' = \frac{1}{2}n$; if the observer is moving in the direction of the wave motion, $n' = 0$; if in the opposite direction, $n' = 2n$.

To return to Doppler's paper: after establishing the formula he takes sound as an example and shows that to raise the pitch of a note from C to D the observer must move towards the source with a velocity of about 136 ft/sec. A velocity of 8 ft/sec should be sufficient to produce a perceptible effect; but, says Doppler, 'I will now proceed to my true object and apply these considerations to light.'

The whole continuous spectrum will be shifted towards the blue if the source approaches us, towards the red if it recedes; and to make a body emitting white or violet light invisible the source will have to recede from us with a velocity of $19/42 = 0{\cdot}45$ that of light. This false conclusion is based on a fallacy which pervades the whole of Doppler's discussion of the changes of colour of moving stars. Knowing, apparently, nothing of the effects which had been already found beyond the red and beyond the violet by F. W. Herschel and by J. W. Ritter respectively, he believed the spectrum to be a band of frequencies terminating at the red and violet, so that a suitable receding motion of the source would shift, for example, the violet to the blue, where the observed spectrum would end. If the velocity were sufficient to shift the violet to just beyond the red, no light at all would be perceived by the observer. To obtain the velocity just quoted he took as the frequency of the extreme red and as that of the extreme violet figures not very different from those of Thomas Young [2].

Arguing on the basis of a limited spectrum and considering the relative brightness of different parts of the continuous spectrum, Doppler concluded that, with a source of white light, such as he considered all stars to be, a velocity of 33

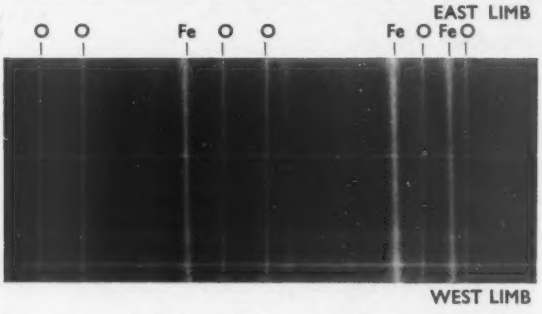

FIGURE 2 – *Doppler effect due to the Sun's rotation. The sharp absorption lines* (O) *are due to oxygen in the Earth's atmosphere and so show no effect. The lines* (Fe) *due to iron in the Sun's photosphere are displaced to the violet at the east limb of the Sun, which is approaching us, and to the red at the west limb, and so are sloped with reference to the oxygen lines.* (*By courtesy of H. H. Plaskett.*)

Austrian miles (152 English miles) per second towards or away from the observer would produce a change in colour perceptible to the eye. A velocity of 860 English miles per second would produce a strong change in colour. Stars with line of sight velocities, then, of from 152 to 84 000 miles per second should show changes of colour, the more notable the greater the velocity: with higher velocities still they should become invisible.

Doppler then produces nine arguments from astronomical observation as examples of the effect of stellar velocities on colour, invoking both double stars and variable stars. For instance, he says that with double stars where one component is much larger than the other the major star is nearly always white, the minor coloured: when the two components are about equal, both are coloured, one pertaining to the short-wave half of the spectrum, the other to the long-wave half. He also states that, in the fifty years separating the observations of Herschel the elder from those of Struve, the colours of the double stars γ Leonis and γ Delphini changed. All such matters, and even the occurrence of new and the vanishing of old stars, he attributes to velocity effects. Needless to say, none of the effects arose from the cause to which he attributed it. His general argument and his enunciation of the Doppler principle were correct, and the effect in the case of sound which he adduced as an illustration was correct, but the particular phenomena of stellar colour to explain which his whole effort was directed have nothing to do with the Doppler effect.

Tyndall in his celebrated book 'Sound', first published in 1867, after describing the mechanism of the Doppler effect for sound, says 'This is the basis of Doppler's theory of the coloured stars. He supposes that all stars are white, but that some of them are rapidly retreating from us, thereby lengthening their luminous waves and becoming red: others are rapidly approaching us, thereby shortening their waves, and becoming green and blue. The ingenuity of this theory is extreme, but its correctness is more than doubtful.'

The validity of even the general principle was not universally accepted by men of science, the chief antagonist being Petzval, celebrated for his work on lenses, whose opposition, based upon a misunderstanding of the problem, began in 1852 and continued for some years. The effect was soon verified in the case of sound, first of all, in 1845, by Buys-Ballot [3], who used an open carriage pulled by a locomotive along a straight stretch of railway to carry his moving source or observer. The source was trumpets blown by skilled players, the observers trained musicians who estimated the changes of pitch by ear. He used both trumpets in the car and observers by the side of the track, and observers in the car and trumpets by the side of the track. Needless to say, the noise of the locomotive caused some trouble, but the results agreed with the theory as well as could be expected. Incidentally, Buys-Ballot put forward criticisms of Doppler's assertion that the eye could detect differences of colour due to the movements of stars, to which Doppler replied. Acoustic experiments on the same lines were carried out in England by Scott Russell in 1848 [4]. More accurate were the tests made by H. C. Vogel in 1876 [5], using a locomotive with a whistle that gave a particularly pure tone. The notes of the approaching and of the receding whistle were matched on a violin.

Fizeau [6], to whose important paper later reference will be made, devised an ingenious laboratory experiment to demonstrate the effect. A wheel 1 metre in diameter carried a card fixed radially, and teeth on a short arc were arranged, above and below, so as to be struck by the card when the wheel rotated. Thus the card, when set in vibration by one set of teeth, constituted an approaching source to an observer in the plane of the wheel's rotation and, when set in vibration by the other set, a receding source. In this way the experimenter obtained differences of tone of a major third (ratio 5 : 4), which agreed very well with the value calculated from the velocity.

A simple demonstration devised by K. R. König [7] about 1865 is of interest as illustrating the method of a very recent application of the effect with radio waves, to be mentioned later.

Two similar tuning forks were adjusted to give four beats a second when sounded together. If one remained stationary while the other was moved at uniform speed towards the ear, the number of beats changed, increasing or decreasing according as the moving fork was the graver or the acuter of the two. The point is that with this method of beats, which is so sensitive to frequency changes, a velocity very small compared with the wave velocity is sufficient to give a detectable effect. With König's forks, of frequency 512, a velocity of 2 ft/sec gave a change of one beat per second: with a frequency of 1024, 1 ft/sec would have sufficed to produce such a change. The higher the frequency, the smaller the velocity, relative to the wave velocity, that can be detected.

Laboratory demonstration of the effect with light is, of course, much more difficult than with sound, but was carried out by Belopolski about 1900 [8]. He took advantage of the fact that, with multiple reflection of light from a source between two approximately parallel mirrors, the effect of the velocity of each mirror is multiplied n times at the nth reflection. Two wheels were used, rotating in opposite senses, each carrying a number of radially mounted mirrors, the number merely serving to increase the intensity. The Fraunhofer lines of sunlight were taken as the standard frequencies to be modified by reflection at the moving mirrors. With the radius in question (about 22 cm) and the speed of rotation (about 44 revolutions per second) four reflections, occasionally six, could be effectively used. Fair agreement with theory was obtained. In the repetition of the experiment, with better spectroscopy, carried out by Prince Galitzin and J. Wilip in 1907 [9], the observed displacement of the mercury lines which they used agreed within 5 per cent with that calculated from Doppler's formula. Majorana, using a modified wheel apparatus of the same type, verified the principle with somewhat greater accuracy in 1918.

The Doppler effect for light was established in the laboratory in a less troublesome manner by Fabry and Buisson in 1919 [10]. They used a disk of white paper, only 16 cm in diameter, which rotated about a vertical axis at approximately 200 turns per second, so that the diametral velocity was only a third of a millionth of that of light. The light sources were two spots, at opposite ends of a fixed diameter, illuminated by a mercury lamp. Observation was made in a direction normal to the line joining the bright spots and very oblique to the plane of the disk, so that the sources were small and bright and the full velocity was effective. The difference of frequency of the light from the approaching and from the receding spot was measured by means of the Fabry-Perot interferometer, thanks to the sensitiveness of which the experimenters were able to verify the effect within an accuracy of 3 per cent—an extraordinary feat with such low velocities.

So much for the experimental establishment of the effect. Of prime importance for the applications to astronomy was a paper by Fizeau, whose name is known to all physicists for his measurements of the velocity of light. It was read to the *Société Philomathique* in 1848 but was, however, not published in full until 1870 [6]. It contains an account of the sound experiment already mentioned. Proceeding to consider the case of light, Fizeau proposes that sharp spectral lines should be used to give the frequencies whose modification is to be measured and suggests that their deviation should be observed with a prismatic spectroscope. He calculates that for a line in the region of sodium D a velocity equal to that of Venus should produce a deviation of 2·65″, which can be doubled by turning the prism through 180°, and specifically says that the radial velocity of distant stars could be measured in this way. He goes into the practical difficulties: the light of the star being feeble, a prism covering the whole objective would be needed, and it is difficult to get so large a prism homogeneous. He concludes '*Il est donc permis d'espérer que ce genre d'observation sera possible et que l'expérience pourra prononcer sur la réalité des phénomènes indiqués.*' This clearly foreshadows the correct method of applying the effect to astronomy, in contrast to Doppler's impossible contentions. Fizeau makes no mention of Doppler. Incidentally, Belopolski and others call the law in question the Doppler-Fizeau principle.

The first practical astronomical applications were published in 1868 by Sir William Huggins [11]. After consulting Clerk Maxwell he made measurements on Sirius, selected as the brightest star in the heavens, using the F line of hydrogen, from the displacement of which he deduced a recession at about 29 miles per second. This was before the application of photography to spectroscopy, the position of the line being taken with a micrometer. In the following year he measured in the same way the radial velocities of several other stars, some approaching, and others receding from, the Sun. The measurements were not, in the light of modern work, particularly accurate, but were of importance as establishing the method. The first really reliable results were obtained by

H. C. Vogel [12] in 1888, using the photographic method. Since then striking improvements in the telescope, the spectroscope, and the photographic plate have made it possible to work with much greater accuracy, and velocities of 1 km/sec can be measured. The radial motion of several thousand stars has been recorded. The Doppler shift to the red in the spectra of nebulae has been much studied as evidence for an expanding universe. In the case of the remotest observed nebulae the velocity of recession somewhat exceeds one-fifth that of light, so that the change of wavelength exceeds 20 per cent, corresponding to a marked change of colour such as Doppler originally anticipated for his stars.

The effect has also been applied to the rotation of the Sun (figure 2). The spectral lines in light from the eastern limb of the Sun are found to be displaced towards the violet as compared with those from the western limb, which is clearly the consequence of a rotation such as makes the eastern limb approach the Earth, the western limb recede. The shift is very small, the difference between the light of eastern and of western origin being only about 1/75 000 of the wavelength of the line used, which corresponds to a velocity of approach and recession of about a mile and a quarter per second, or one rotation in about 25 days (figure 2). The intensity of the solar light permits greater dispersion than is possible with stellar light, so that considerable precision is possible. The rotation has been measured in various latitudes, with very interesting results. The rotation of the rings of Saturn and of various planets has also been measured by the same general method.

Reference must further be made to binary stars whose nature has been revealed by the Doppler effect in the light from the two components which are too close to be resolved telescopically. It is clear that the periodic variations of the Doppler displacements give the period of these stars, the so-called spectroscopic binaries. The first to be announced was discovered by E. C. Pickering [13] in 1889, namely Mizar (ζ Ursae Majoris). The period was 104 days. Today thousands of spectroscopic binaries are known, some with periods of less than a day. Enough, perhaps, has been said to indicate the great part played by the Doppler effect in modern astronomy.

An important terrestrial application of the Doppler principle with light was demonstrated in 1905 by Johannes Stark [14], when he obtained the effect with canal rays (positive rays) in a hydrogen discharge tube. He found that with observation normal to the direction of the rays the Balmer lines of the hydrogen spectrum had their normal frequency and character: if, however, observation were made from a position such that the rays were travelling towards the spectroscope, the lines were broadened towards the violet, while if observation were made from the opposed direction, there was a broadening towards the red. The general effect, then, corresponded to what was to be expected if the moving particles were radiating the lines, the continuous nature of the broadening being due to the fact that, owing to collisions, the light-emitters had all possible velocities up to the maximum. The extent of the broadening enables the maximum velocity of the luminous particles to be determined, which is less than that calculated from the applied potential on the supposition that unhindered acceleration takes place. The Doppler effect is pronounced, since it is easy to obtain in the discharge tube velocities of some thousandths of that of light.

Much work was carried out by Stark and others, notably Rau, on this effect with various gases, work which was, at the time, very important for the evidence which it supplied as to the electrical state of the atoms emitting arc and spark spectral lines and of the molecules emitting band spectra. When Stark was awarded the Nobel Prize in 1919 the main reference in the citation was to his 'epoch-making' investigations of the Doppler effect with canal rays, the Stark effect being mentioned as supplementary.

In any luminous gas, ordinary thermal agitation means that the atoms or molecules concerned in the emission are moving in all directions and should therefore show a Doppler effect manifesting itself as a broadening of the line in question, symmetrically, since as many sources are approaching as are receding. The effect should, however, be very small, since, for instance, the average velocity of a hydrogen atom at 100° C is about a hundred-thousandth of that of light. As a precise measure of the effect, what is termed the half-intensity breadth is used. As an example of the magnitude, for a sodium D line at 300° C this Doppler broadening is about 0·02 Å, or 1/300th of the distance between the D lines. This is easily measured with modern spectroscopic technique. On account of the smaller atomic weight the hydrogen lines under like conditions are broader. For very accurate spectroscopic work these lines have been made sharper by working with the discharge tube in liquid air. At the other extreme, the Doppler broadening has come into prominence in

connection with the famous ZETA, where it has been used to estimate the temperature in the discharge [15]. The breadth of the lines as measured here is in the region of 1 Å.

In a completely different field, the Doppler effect has recently been applied with great success to aerial navigation, where a main problem has always been to measure ground speed. The older types of instrument give speed with reference to the air, and, the local wind speed being frequently not known with any great precision, fail to provide accurately the desired location. König's tuning fork experiment, where a movement with a speed a thousandth of that of sound altered the beat frequency perceptibly, supplies the principle. Suppose that an aircraft sends out two beams of radio waves, one forward and one backward, directed downward sufficiently to be reflected (or, more correctly speaking, scattered) back to the source from the ground at not too great a distance. The Doppler effect due to the moving source will make the frequency of the reflected forward beam a little higher, that of the reflected backward beam a little lower, than that of the emitted wave, the magnitude of the change of frequency being proportional to the speed of the aircraft. These two slightly different frequencies, received by the aircraft, will produce by their interaction a comparatively low frequency oscillation. By modern methods of instrumentation, involving a phonic wheel, the periodicity of this low-frequency oscillation strictly controls the speed of revolution of a motor, which, by further ingenious mechanism, is made to furnish the pilot with direct reading of the ground speed and the distance flown. To measure the drift the two beams are swung so that one goes down to port, the other to starboard, the information being made available in a like manner.

A numerical example may be helpful. In an actual Marconi installation the frequency of the emitted wave is 8800 Mc/s. Since reflection is in question, the effect due to the movement of the aircraft, which is both source and receiver, is doubled. On the other hand, if the beam is directed downwards at 60° to the horizontal, which is about the angle used, the velocity of the aircraft, flying horizontally, resolved along the beam is halved, so that all that need be considered is the normal effect due to a source moving in line with a stationary receiver. If the velocity of the aircraft is 335 m.p.h., which is about a two millionth of that of light, the increase of frequency of the reflected forward beam will be 8800/2 = 4400 c/s, and the decrease of frequency of the reflected backward beam will be 4400 c/s, so that the beat frequency will be 8800 c/s, that of a high audible note, about five octaves above the middle C. This is low enough to control the speed of rotation of the motor that works the gear.

A last instance of present-day applications is the use of the Doppler effect to track artificial satellites circling the earth. The transmitter carried by the satellite sends out a continuous wave of fixed frequency, the modifications of which, as detected by the observer, are used in the manner recently described in ENDEAVOUR [16].

The history of the principle is, then, a strange one. It was put forward over a hundred years ago by Doppler with the sole object of explaining the colour of stars, but the deductions from observational evidence which he marshalled to support it were completely erroneous. Some decades later it was proved to have astronomical applications of importance, which increased as time went on, and in recent times it has risen to the position of providing the main observational evidence for an expanding universe. In textbooks of physics it is mainly handled in connection with sound, of which aspect daily life provides many examples. In the last year or so it has played a part in the astonishing attempts to demonstrate a nuclear fusion reaction, in advancing aerial navigation, and in tracking man-launched satellites. The modest Austrian would be astonished to see the scope and importance of work which in his lifetime aroused but little attention.

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The surfaces of plants

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The wettability of leaf surfaces varies from plant to plant and has considerable practical importance—the efficiency of chemicals applied to leaves may ultimately depend on it. New techniques in electron microscopy have made it possible to resolve the ultra-structure which largely determines wettability, and the techniques and results are discussed here.

Interest in the behaviour of liquids on leaves was stimulated by the increasing use of sprays in agriculture and particularly by the discovery of weed-killers of the growth-regulator type. The differences in susceptibility to these hormonal weed-killers may be due to some plants shedding the droplets from their surfaces and thus failing to absorb them. This may be caused by the posture of the leaves, their shape, or the unwettability of the surface.

The degree of wettability may be measured by the angle of contact between the liquid-air surface and the solid. The wettability of a solid by a liquid is dependent on the interaction between the liquid molecules and the chemical groups exposed on the solid surface, and also on the texture of that surface [1]. The highest contact angle for a plane surface of a naturally occurring substance is probably not above 105°. However, many plants have apparent contact angles on their leaves and other surfaces far above this figure. The angle may vary considerably from one part of the plant to another and may also be subject to diurnal changes, as shown by G. E. Fogg [2].

A few of these high values are due to macroscopic or microscopic morphology, as in *Juncus inflexus*, which has a smooth waxy cuticle folded into ridges, or as in *Salvina*, which has curious microprojections on the leaf surface.

In the majority of species the surface roughness responsible for the high contact angle lies beyond the resolution of the microscope, and attempts have been made to utilize the electron microscope. The low penetrating power of the electron beam prevents its being used for the direct observation of a surface. An attempt to circumvent this by using reflection electron microscopy was made on insect cuticle [3]. However, the usefulness of this technique is limited by the resolution being only a little above that of the light microscope, and by the severe distortion of the image which makes interpretation difficult. The problem of looking at so solid an object as a leaf in the electron microscope can be obviated by using a surface replica. A negative mould of the surface is made of a material that is transparent and inert in the electron beam. This may be viewed directly (the negative replica) or a cast may be made of this negative replica, of the thickness required, and this positive replica examined in the microscope. There are a number of materials that can be used to make surface replicas, including certain plastics [4, 5].

This technique necessitates wetting the leaf surface. This can be avoided by using evaporated carbon as the replica material [6]. Carbon is completely inert, is non-crystalline, can replicate detail down to the 1 mμ level, and, unlike conventional plastics, can replicate biologically 'moist' surfaces. Either a pseudo-replica or a true replica is produced. In the first instance, parts of the original surface remain embedded in the carbon layer (figures 1 and 3); in the latter (figure 2) a true replica consisting of carbon only is formed. Either picture can easily be interpreted.

The replicas reveal minute projections from the surface of the cuticle in many plants. These projections are assumed to be of wax extruded through the cuticle. They are of many different forms and may be characteristic of the species, the genus, or even the family; but although A. de Bary [7], as early as 1871, grouped the types of wax structures to be found on leaves, no classification yet seems to be possible with this technique. All the forms of *Brassica oleracea* look very much alike (figure 1). The garden pea (figure 21) resembles the white lupin (figure 4), but so also does the quite unrelated *Galanthus nivalis*, the snowdrop (figure 9). *Chrysanthemum segetum* (figure 3), on the other hand, looks totally unlike any other species of *Chrysanthemum*.

The surface ultrastructure is not necessarily the same all over the plant. Figures 21, 11, and 12 show the adaxial, abaxial, and stem surfaces of a

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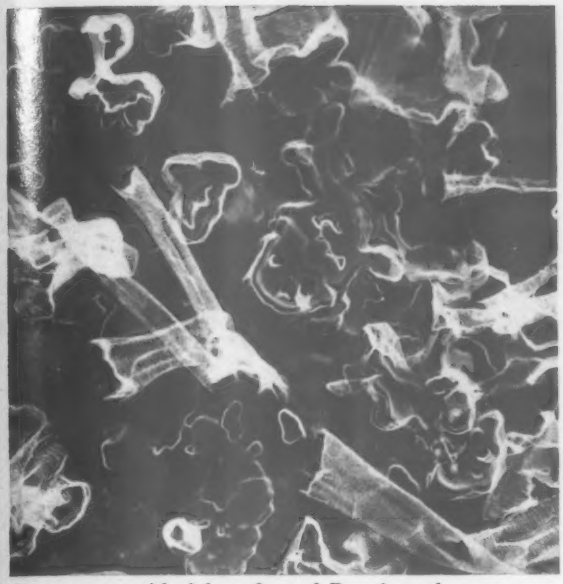


FIGURE 1 – *Adaxial surface of* Brassica oleracea var. capitata.

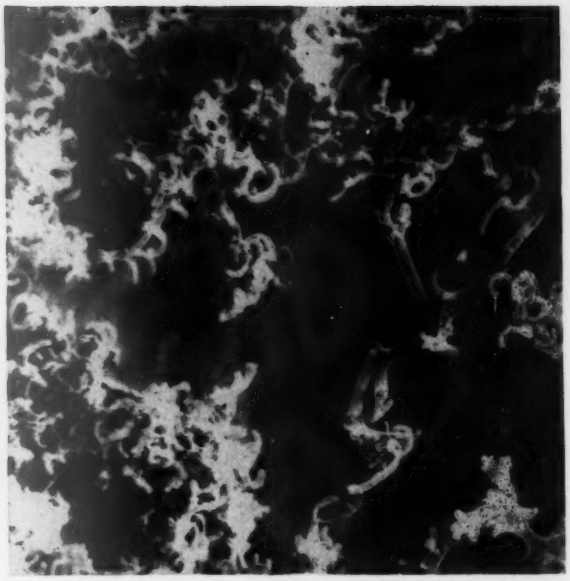


FIGURE 3 – *Adaxial surface of* Chrysanthemum segetum.

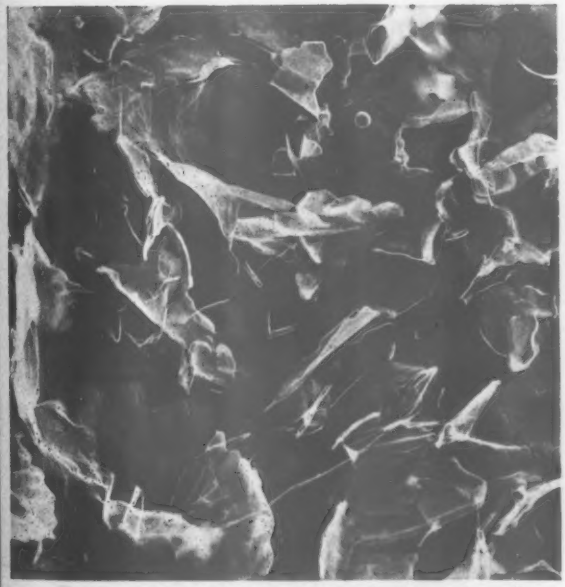


FIGURE 2 – *Adaxial surface of* Hyacinthus orientalis.

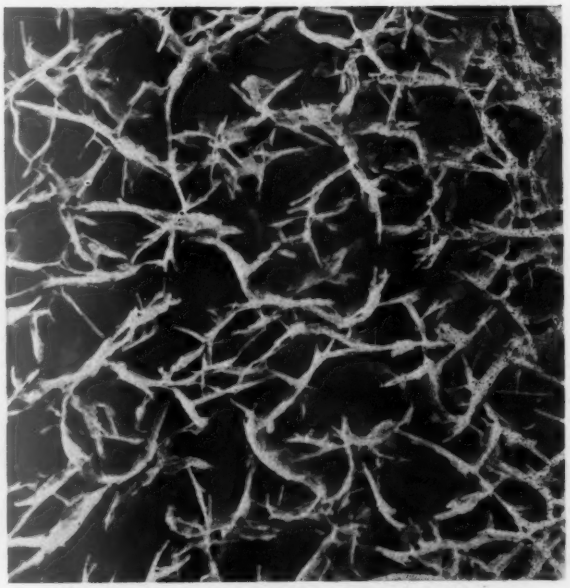


FIGURE 4 – *Adaxial surface of* Lupinus albus.

Carbon replicas of leaf surfaces × 10 850.

FIGURE 5 – *Adaxial leaf surface of* Kleinia articulata.

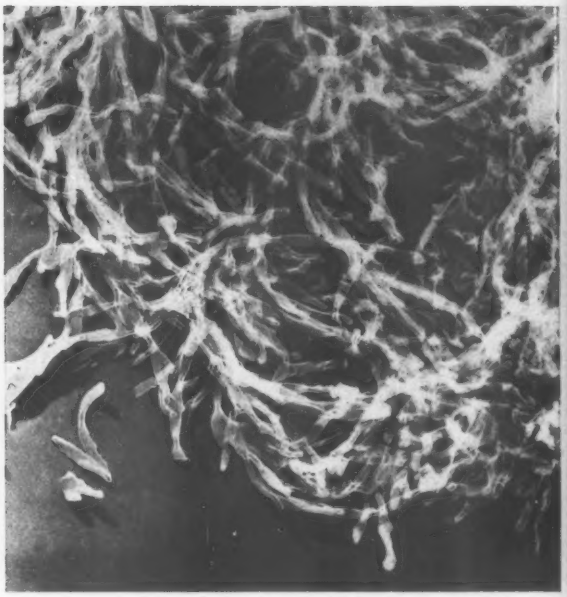


FIGURE 8 – *Stem surface of* Kleinia articulata.

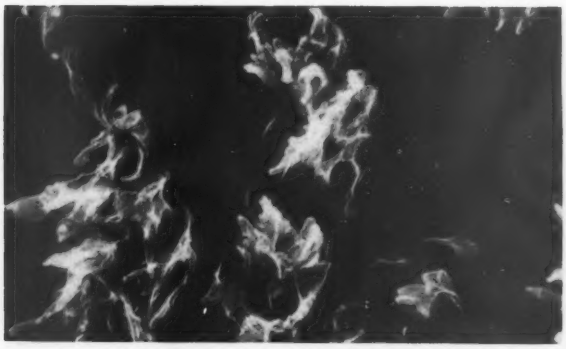


FIGURE 6 – *As above, after one second's immersion in distilled water.*

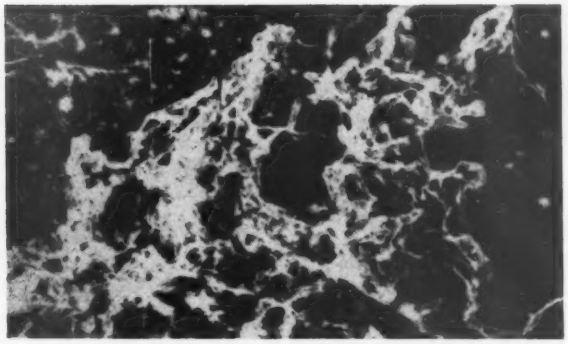


FIGURE 7 – *As above, after ten seconds' immersion in distilled water.*

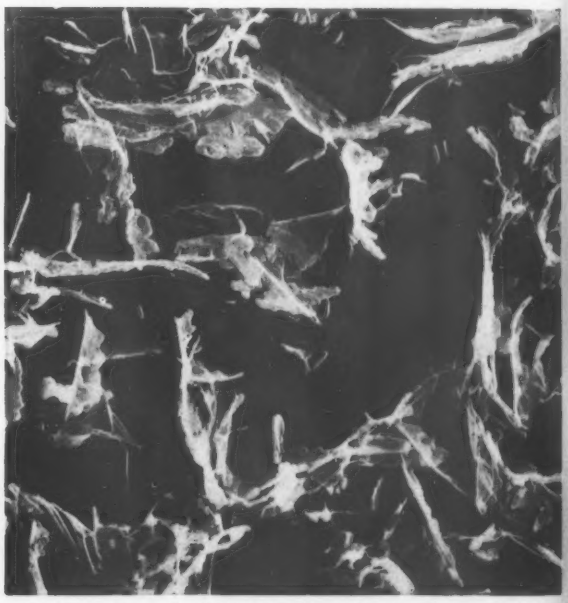


FIGURE 9 – *Adaxial leaf surface of* Galanthus nivalis.

ACKNOWLEDGMENTS

I am grateful to Miss Joan Sampson for taking the electron micrographs and to Sir Paul Fildes, F.R.S., for electron microscope facilities in the Sir William Dunn School of Pathology, Oxford.

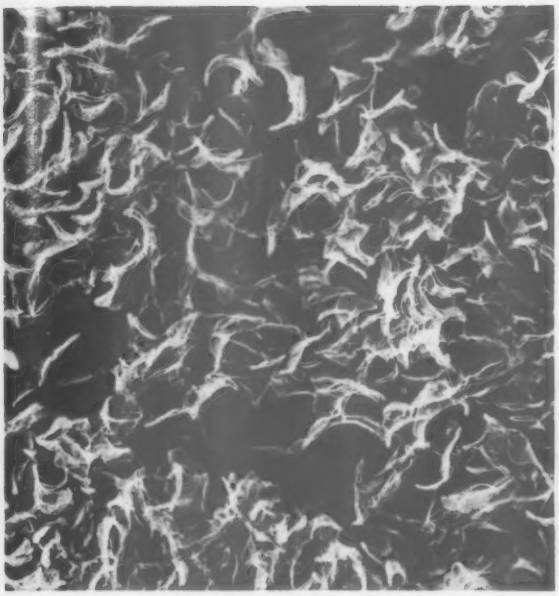


FIGURE 10 – *Adaxial leaf surface of* Bryophyllum tubiflorum.

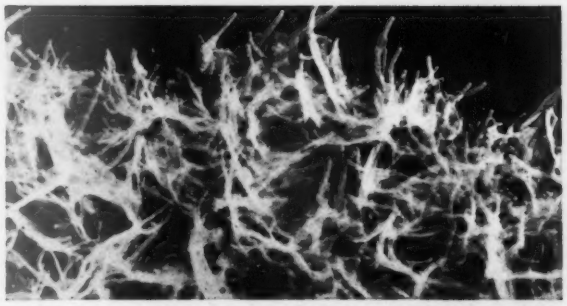
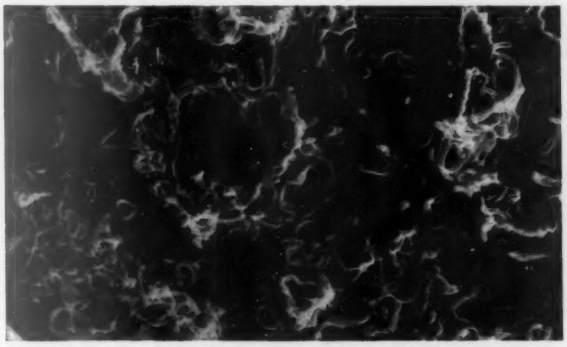


FIGURE 13 – *Adaxial leaf surface of* Lupinus albus (*folded replica*).



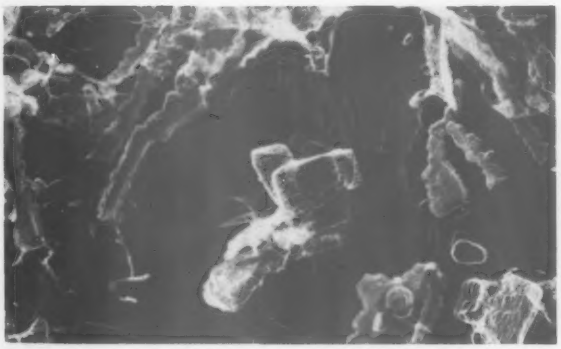
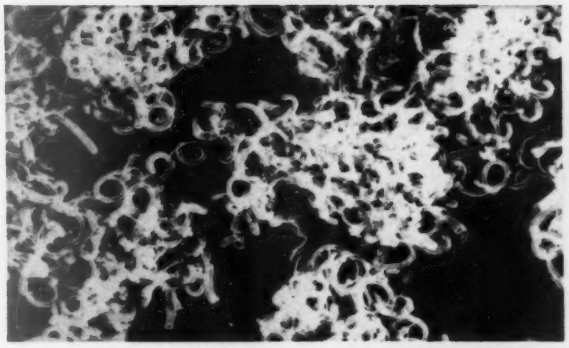


FIGURE 11 – *Abaxial leaf surface of* Pisum sativum.



FIGURES 14 (*upper*) *and* 15 – *Adaxial leaf surfaces of* Chrysanthemum segetum *immediately after brushing and seven days later respectively.*

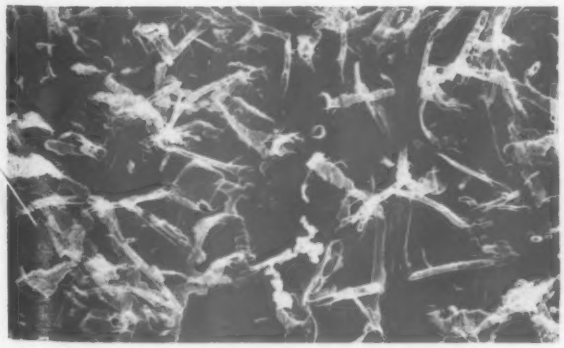


FIGURE 12 – *Stem surface of* Pisum sativum.

FIGURE 16 – *Adaxial surface of* Pisum sativum *grown in wind tunnel at* 25 *m.p.h. wind speed.*

Figure 17

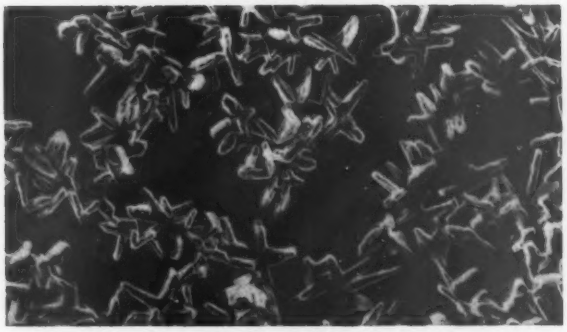


Figure 18

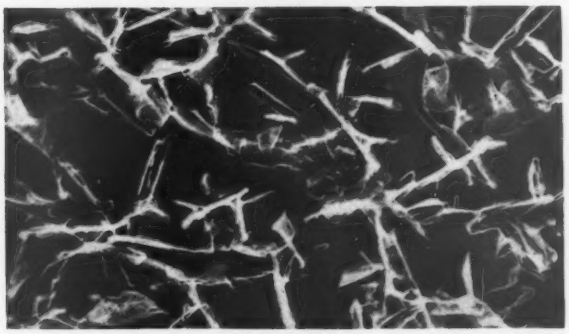


Figure 19

Figure 20

FIGURES 17–20 – Pisum sativum *grown in darkness to second leaf stage. Fig.* 17*:* 24 *hours after transfer to light. Fig.* 18*:* 48 *hours after transfer. Fig.* 19*:* 72 *hours after transfer. Fig.* 20*:* 7 *days after transfer.*

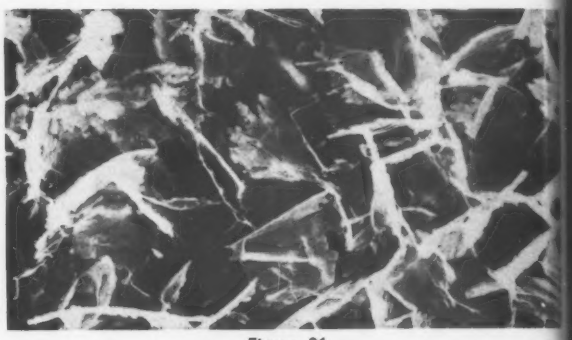


Figure 21

Figure 22

Figure 23

Figure 24

FIGURES 21–24 – Pisum sativum. *Fig.* 21*: grown at* 5000 *ft.candles light intensity. Fig.* 22*: at* 1500 *ft.candles. Fig.* 23*: at* 900 *ft.candles. Fig.* 24*: grown in darkness.*

pea, and figures 5 and 8 the leaf and stem surfaces of *Kleinia articulata*. As a general rule the cotyledonary leaves are smooth even in plants which have a highly complex surface structure on other organs. The high degree of resistance to weed-killers possessed by *Chrysanthemum segetum* may be due to the occurrence of wax projections over all aerial parts of the plant, including cotyledons, petioles, stems, and both leaf surfaces. A further factor may be its ability to recover from mechanical damage. Figure 14 shows an adaxial surface immediately after brushing. Figure 15 shows a corresponding leaf seven days after similar treatment, when the wax projections have regenerated.

Under field conditions surfaces are not usually damaged so severely. Surfaces such as those represented in figures 3, 4, and 21 are moderately or extremely resistant to weathering, and the leaves maintain high contact angles until senescence. On the other hand, surfaces like those in figures 1, 2, 5, and 10 are very easily damaged and may only remain unwettable for a few days. The cause is usually simple mechanical damage such as breaking off or flattening of the minute projections, but figures 6 and 7 show the effect of immersing a leaf of *Kleinia articulata* in distilled water for one second and ten seconds respectively. The surfaces of the other plants illustrated do not seem to be affected in this way by water. The indirect effect of other environmental changes may be just as striking. Figures 21–24 show the effect of reducing the intensity of light falling on the leaf surfaces of peas. The contact angle falls with the decrease in surface wax development, and this may assist in explaining the increased susceptibility of weeds growing under crops and sprayed after harvesting. Another change due to the environment is that leaves subjected to high wind speeds seem to develop a more dense and compact layer of wax projections. (Compare figure 16 with figure 21.)

A number of compounds, e.g. trichloracetic acid, are used in agriculture for treatment of the soil before germination and increase the susceptibility of some weeds to herbicides. Under the electron microscope it is seen that the wax projections are reduced progressively in size with increasing concentration of treatment and present a surface which is less water-repellent [8].

The method of development of these projections is difficult to understand. A number of surfaces have projections with an annular sculpturing suggesting some form of phasic growth (figures 1 and 11). Since it is impossible to make replicas of leaves smaller than about 3 mm, a study of the development of the surface from the primordial stage is not yet possible. The youngest leaves that can be studied have surfaces similar to those of mature leaves. To gather some idea of the course of development of the wax, peas can be grown in darkness to the second leaf stage. In darkness no wax projections are formed at all, but they develop quite rapidly after transfer to the light (figures 17–20). The transition from one stage to another is difficult to explain, because we must presume a continuous reorganization of the surface. Moreover no pores or apertures from which projections such as those in figures 2 or 8 could be derived have ever been resolved, and they must have been extruded as liquids.

There is a complete agreement between the occurrence of such projections on the surfaces as seen under the electron microscope and contact angles above 105° recorded on those surfaces, although for the reasons given these high values may not be permanent. An impression of a transverse section of a leaf at this level of resolution is given in figure 13. In this instance the carbon film has bent over and has been photographed at right angles to the normal plane of viewing, giving a transverse view. This shows how a droplet must be held away from the cell wall by the projections.

The view that everything external to the epidermal cells is static can, on the present evidence, no longer be held. We must presume that since the density of projections on the very young leaves is the same and not higher than that on the mature leaves, production of surface wax continues until leaf expansion has ceased. This, and the evidence of recovery from mechanical damage and changes to environmental conditions, indicate that there must be a continuous passage of substances through the cuticular layers.

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Palaeomagnetism and ancient wind directions

N. D. OPDYKE and S. K. RUNCORN

Study of the direction of magnetization of rocks shows that the continents have changed their distances from and their orientations relative to the geographical pole. It is very desirable to confirm the positions revealed by this work. One method is to use the record of the directions of the trade winds of ancient geological times as preserved in aeolian sandstones. The methods used in both of these approaches, and the extent to which they confirm one another, are discussed with reference to both hemispheres in this article.

In a previous article in ENDEAVOUR, S. K. Runcorn [1] described the developments in the study of rock magnetism that have been made in recent years. Strong evidence was advanced that about the time of their formation certain igneous rocks, mainly lavas, and some sediments, mainly red sandstones, acquired a magnetization which has remained substantially unchanged. The magnetization of a rock series of a particular geological age shows a remarkable consistency even over hundreds of miles, and there is reason to believe that this remanent magnetization represents the mean direction of the geomagnetic field at that time, allowance having been made for any tilt the rocks have acquired since formation. It was found that in Great Britain, where a widespread survey of this type was first made, that there has been a gradual change of the mean direction of the field through geological time and that only in Cainozoic times (the last sixty million years) does this mean direction coincide with a field symmetrical about the present axis of rotation of the earth.

The earth's magnetic field today is nearly, but not exactly, the same as would be produced by a small, powerful magnet or 'dipole' at the earth's centre orientated with its axis coincident with the geographical axis. From historical observations it is known that the field changes irregularly, and from these observations alone one would suspect that the mean field over a time of the order of a thousand years would be much more nearly that of an axial dipole than is the field at the present time: the theory of the geomagnetic field gives strong support to this supposition. Consequently it is possible to determine from the mean direction of magnetization of a rock formation, sampled over a sufficient thickness to remove the effects of this 'secular variation', the positions of the poles with respect to the site during the corresponding geological time.

The determination of the pole position is a very important step in rock magnetism studies, and it is desirable to explain in more detail how this is done. Figure 1 shows the direction of the field at the surface of the earth due to a dipole at the geocentre. The angle of inclination is the angle made by the direction of the field with the horizontal and varies from zero at the equator to a right angle at the pole. A simple formula relates the angle of inclination to the latitude (λ). A great circle through the direction of magnetization of the rock, after correction for geological tilt,

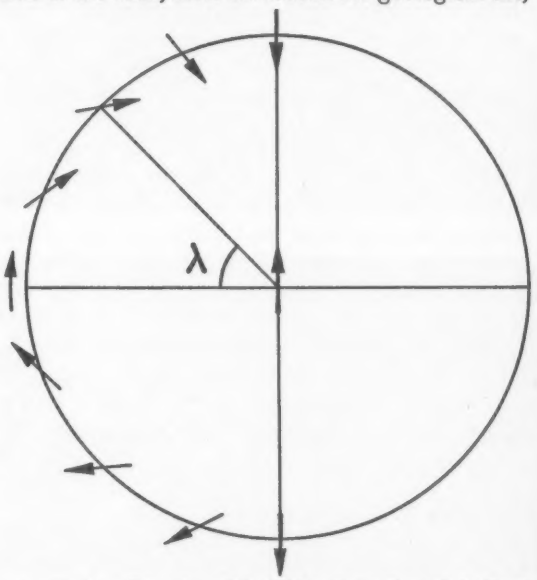

FIGURE 1 – *Direction of the field at the surface of the Earth due to a dipole at the centre. (From 'Geomagnetism', Vol. 1, by S. Chapman and J. Bartels, p.105. Oxford University Press, 1940.)*

is constructed. From the latitude the position of the pole on this great circle is easily determined.

The survey of the palaeomagnetic directions for different geological ages and different continents has now advanced considerably. When the article referred to [1] was written it had been shown that the pole positions in successive geological periods for Great Britain lie on a reasonably smooth curve and that they lie successively nearer the present pole as the age of the period diminishes. This may be interpreted either as a motion of Great Britain relative to the rest of the earth or as a movement of the axis of rotation relative to the earth. The latter, termed polar wandering, would probably have occurred if internal motions had taken place in the earth's mantle and if the spheroidal shape of the earth could have changed, over periods of the order of millions of years, into shapes appropriate to the new positions of the axis of rotation. Thus at first it appeared possible that the rock magnetism results could be explained by polar wandering alone.

The polar wandering curves derived from other continents should in this case have been in agreement. Although that for North America was similar in shape to that for Europe, Runcorn [2] showed that the American curve lay significantly west of the European one, as shown in figure 3 [3]. Consequently it appears that late in Mesozoic times North America moved about 20° west relative to Europe. Such relative movement of the continents, presumably involving the basaltic floor of the oceans, is postulated in a theory known as continental drift which some geologists advanced long ago.

Recently E. Irving and R. Green [4] have shown that the polar wandering curve for Australia lies almost as far away as it possibly could from the polar wandering curves for North America and Europe. This curve lies across North Africa and joins the present pole from the North Atlantic. Both of these surprising discrepancies are more acceptable when it is noted that, in general, the palaeomagnetic results from a continent give values of its latitude at the time of the formation of the rocks, which latitude, unlike the present latitudes, shows no conflict with the palaeoclimatic indications obtained from geology. In Australia, for example, Irving and Green find (figure 2) that at the times when the position of Australia, inferred from the palaeomagnetic data, was near the pole in the Permo-Carboniferous and the late Pre-Cambrian, geological evidence indicates that Australia suffered widespread glaciations. Similarly the great deserts of late Palaeozoic and early Mesozoic times in North America and in North Europe are paralleled in the palaeomagnetic evidence by nearly horizontal magnetizations, from which a position close to the equator is inferred (figure 13).

It may be asked whether it is possible to show that the directions of the magnetic field deduced from the palaeomagnetic measurements are consistent over very considerable areas. Not as many relevant measurements are available as one would like. Almost every rock formation that has yet been studied extends over hundreds of miles, and there is certainly persistence over this range in the palaeomagnetic directions. It is much more interesting, however, to consider whether the palaeomagnetic measurements of rock formations of the same age across an entire continent indicate the same place for the poles. In this connection it must be noted that the polar wandering curve indicates a movement of the pole of about one-third of a degree per million years, and consequently during a geological period it is quite possible that the pole motion (apart from the secular variation, which is assumed to be smoothed out in all cases) could lead to differences of up to 20 or 30 degrees in the palaeomagnetic directions of rocks of the same geological period. Unfortunately the rocks that have been used so far in palaeomagnetic studies are those in which fossils are most scarce, and consequently the determination of their geological age to any time very much shorter than a geological period seems difficult. However, the Upper Triassic of the United States furnishes an example of good agreement between pole positions deduced from widely different areas, as shown in figure 14.

It will be seen that the basic claim made in the interpretation of rock magnetism studies is that palaeomagnetism provides a method of directly establishing the latitude of a site at the time of formation of its rocks. The test of the reliability of rock magnetism methods depends on finding independent methods of determining latitudes in remote geological times. The study of palaeoclimates is the most obvious method.

Now movement of the earth's axis of rotation relative to the land masses will cause different parts of the latter to fall in the trade wind belt. Fortunately sand dunes and aeolian sandstones can in fact be used to show the direction of modern and ancient winds respectively.

SAND DUNES

It is known [5] that barchan dunes are formed

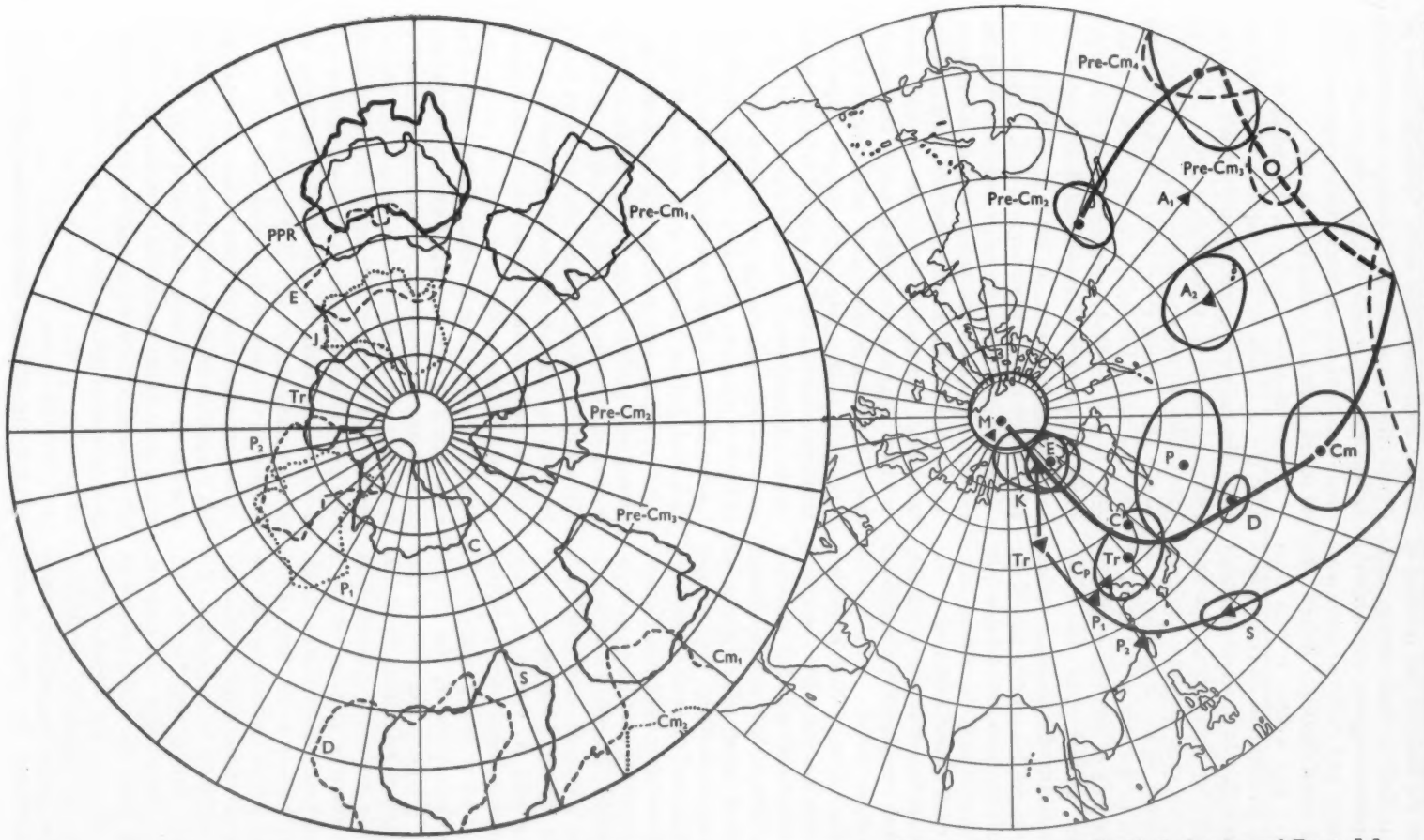

FIGURE 2 – *Positions of Australia relative to the South Pole at various geological times, as deduced from palaeomagnetic evidence. Heavy outline denotes present position of Australia. After Creer, K. M., Irving, E., Nairn, A. E. M., and Runcorn, S. K.* Ann. Géophys., **14**, 492, 1958.

PPR	*Pliocene, Pleistocene, and recent*
E	*Lower Tertiary, probably Eocene*
J	*Mesozoic, probably Jurassic*
Tr	*Triassic, probably lower Triassic*
P_2	*Permian, Upper Marine Series*
P_1	*Permian, Lower Marine Series*
C	*Upper Carboniferous*
D	*Devonian, probably Lower Devonian*
S	*Upper Silurian*
Cm_2	*Middle Cambrian*
Cm_1	*Lower Cambrian*
Pre-Cm_3	*Top of Upper Proterozoic*
Pre-Cm_2	*Upper Proterozoic*
Pre-Cm_1	*Lower part of Upper Proterozoic*

FIGURE 3 – *Polar wandering curves for North America and Europe* [3].

M	*Miocene*
E	*Eocene*
K	*Cretaceous*
Tr	*Triassic*
P	*Permian*
C	*Carboniferous*
C_p	*Carboniferous (Pennsylvanian)*
D	*Devonian*
S	*Silurian*
Cm	*Cambrian*
Pre-Cm	*Pre-Cambrian*
A	*Pre-Cambrian (Algonkian)*

Triangles denote poles determined from measurements on American rocks. Full dots denote poles determined from measurements on British rocks. (Open circle denotes a pole on the other hemisphere.) Thin line denotes approximate path of the pole based on American rocks. Thick line denotes approximate path of the pole based on British rocks. (Dotted lines denote paths drawn on the other hemisphere).

The ovals in this figure and in figure 14 are 95 per cent confidence limits.

Tr Triassic, probably lower Triassic
P_3 Permian, Upper Marina Series
P_1 Permian, Lower Marina Series
C Upper Carboniferous

Cm_1 Lower Cambrian
Pre-Cm_3 Top of Upper Proterozoic
Pre-Cm_2 Upper Proterozoic
Pre-Cm_1 Lower part of Upper Proterozoic

Thin line denotes approximate path of the pole based on American rocks. Thick line denotes approximate path of the pole based on British rocks. (Dotted lines denote paths drawn on the other hemisphere).

The ovals in this figure and in figure 14 are 95 per cent confidence limits.

FIGURE 4 – *Sand dune near Kayenta, Arizona.*

FIGURE 5 (*above*) – *Wingate sandstone* (*Triassic age*), *Colorado River Valley, near Moab, Utah.*

FIGURE 6 – *Navajo sandstone* (*Jurassic age*), *Mount Carmel Highway, Zion National Park, Utah.*

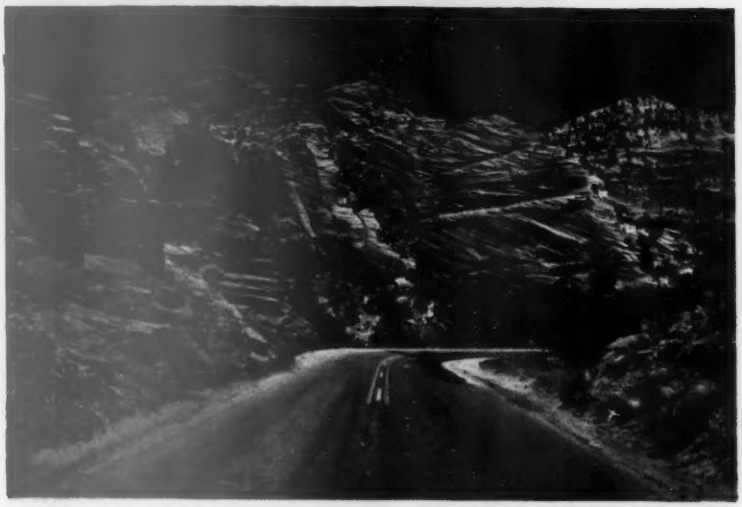

FIGURE 7 – *Weber sandstones (Pennsylvanian age) in Brush Creek Canyon, south flank of the Uintah Mountains, Utah. The height of the man in the left background conveys an idea of the scale.*

FIGURE 8 – *Weber sandstone (Pennsylvanian age) in Sand Canyon, Dinosaur National Monument, Utah.*

FIGURE 9 – *Tensleep sandstone (Pennsylvanian age) in Tensleep Canyon, Wyoming. Photograph taken from the east. Note that the lee slopes dip towards the south, indicating that the wind blew from the north.*

FIGURE 10 – *Sand dunes near Kanab, Utah.*

FIGURE 11 – *Vertical cut through sand dune at Leupp, Arizona (after McKee). The paint-brush gives some indication of the size of the section.*

by steady winds of constant direction in deserts in which the supply of sand is limited. A photograph of one of nearly perfect form is shown in figure 4. The windward slope to the right is a gentle one from which sand is being continually blown, deposition occurring on the steep lee-side slopes. These are crescent-shaped in plan, with the points downwind. On these steep slopes the sand rests at its angle of repose, which is about 33°. The barchan is the simplest form, and where there is more sand transverse dunes are formed. These consist of a sinuous line of steep lee slopes, parts of which resemble barchans. An example is shown in figure 10.

Successive layers of sand deposited on these lee slopes differ slightly in packing or size distribution or in the colour of the sand grains. Thus if a vertical cut is made through a sand dune, traces of these 'bedding planes' may be observed. E. D. McKee [6] has made such observations on a sand dune in Arizona, and figure 11 is taken from his paper.

Similar sand seas to these have become fossilized in the past and are preserved in the geological record as aeolian sandstones. In these sandstones traces of the bedding surfaces on the lee slope remain and can be observed in exposures of the rock made naturally by erosion, or artificially in quarries and in road or rail cuts. It is possible to measure the azimuth and the angle of dip of the line of greatest slope of parts of these bedding planes. The average of the azimuths gives the mean direction of movement of the sand dunes and hence the wind direction. The scatter of the directions depends on the curvature of the lee slopes of the dunes and on the variation of the wind direction.

The process by which a sea of dunes gets preserved is similar to that of any sedimentary deposit, i.e. the lowering of the land relative to sea level and subsequent deposition of marine beds. The sand will become cemented by silica-bearing or carbonate-bearing solutions permeating through it millions of years after its initial deposition. Cycles of wind erosion may occur while the dunes are still exposed and they may be planed down to a nearly flat surface on which later dunes can accumulate. Such presumed erosion surfaces are shown in figure 5 by the well-marked horizontal lines.

In an exposure of aeolian sandstone it is rare to see a large part of a single dune. Usually the vertical face of rock reveals sections through a number of dunes, each at different angles to the lee slope. The trace of the parallel bedding planes from any one dune is known as a cross-bedded unit. Examples of these are shown in figures 5–9.

Unfortunately there is at the present time no simple diagnostic test that can be applied to a sandstone which enables the geologist to distinguish with certainty between an aqueous and an aeolian environment of deposition. But if the following criteria are all satisfied a strong case exists for inferring aeolian deposition:

1. Highly inclined cross-bedding up to the angle of rest of dry sand (33°) occurring in very large units, some of which exceed 50 ft in height (see for example figure 7). Similar cross-bedded structures can be produced by deposition in streams and in the sea as a result of strong currents, but they are usually much smaller in size than dunes and have smaller angles of bedding.

2. The absence, due to winnowing by the wind, of micaceous material. This is due to the fissile nature of these minerals, which causes them to break on impact.

3. The absence of marine fossils, which indicates continental deposition.

4. High coefficients of sorting and roundness, due to the sand's mode of transport. Very small grains of sand will be transported much further than very large grains, and so in any particular dune, grains of one size will predominate. Frequent impacts will round off the grains.

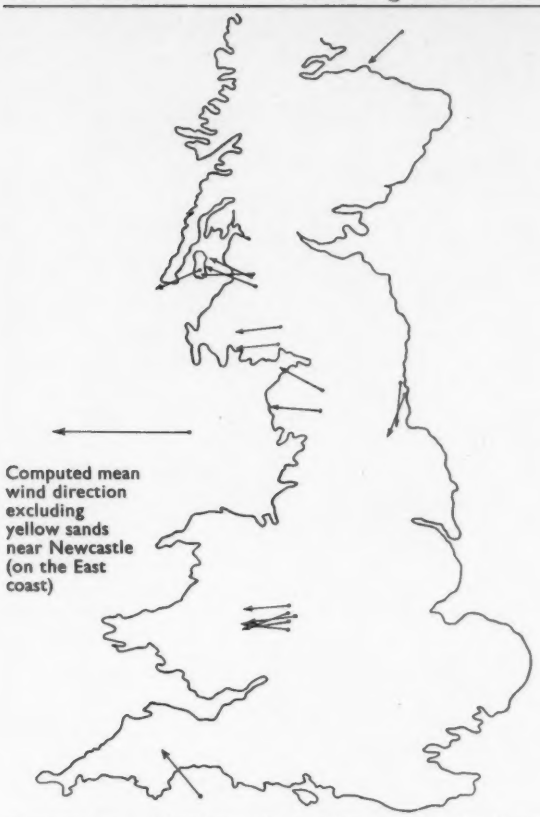

FIGURE 12 – *Directions of prevalent winds in Great Britain for Permian times (after Shotton* [8] *and Opdyke).*

FIGURE 13 – *Directions of prevalent wind in Western United States for Permian and Pennsylvanian times. (Arizona results after Reiche* [10]*; other results after Opdyke and Runcorn,* Bull. Geol. Soc. Amer. *In the press.)*

The method used by geologists to determine the direction of movement of the sand dunes that form the aeolian deposits is a fairly simple one. A compass is placed on the bedding plane that was at one time the front slip face of the sand dune, and the direction of the normal to a level line on this slip face is recorded. This represents the direction in which a portion of the original dune face was moving. If from 30 to 100 of these readings are made, each from separate cross-bedded units, the movement of the sand dunes is obtained by representing each of the directions by an arrow and deriving, rectorially, the mean direction.

OBSERVATIONS IN BRITAIN AND NORTH AMERICA

Extensive palaeodeserts in the northern hemisphere at the end of the Palaeozoic period occurred in England (Triassic and Permian periods) and in the Western United States (Permian and Pennsylvanian periods). The age of these aeolian sandstones is thus 200–250 million years.

The palaeodesert of the Permian of England is typified by the Penrith sandstones of the Eden Valley. This formation was described by J. R. Dakyns, R. H. Tiddeman, and J. G. Goodchild [7]: 'Extended observations upon the directions of false-bedding in the rock show that there is a marked predominance of false-bedding planes inclined, in a general way, from some easterly point towards the west. On the assumption that the Penrith Sandstone is of aeolian origin, this westerly false-bedding may indicate the prevalent direction of the winds during the dry seasons.' More recently F. W. Shotton [8] compiled results from Permian aeolian sandstones from all over Great Britain, and he found that the wind that deposited these sandstones was an easterly wind which varied only slightly from the north of Scotland (Elgin) to the south of England (Devon). These are shown in figure 12.

In North America the Coconino sandstone of

FIGURE 14 – *Upper Triassic pole positions deduced from palaeomagnetic observations at points in Great Britain and the United States.* 1, *Springdale Sandstone, Utah;* 2, *Lavas near Holyoke, Massachusetts;* 3, *Lavas and sediments of Connecticut;* 4, *Newark series, New Jersey;* 5, *Keuper Marls, England* [11].

FIGURE 15 – *Relative position of Europe and North America and positions of pole, equator,* 20°*N,* 20°*S, and* 60°*N latitude lines for late Palaeozoic and early Mesozoic times, deduced from palaeomagnetic observations.*

Permian age of Arizona has long been recognized as an aeolian sandstone [9]. It is a prominent feature just below the rim of the Grand Canyon, where it is a 300 ft thick white deposit and extends as an easily recognized formation over hundreds of miles. P. Reiche [10] examined the directions of cross-laminations of this sandstone, and his results are plotted in figure 13: they show, apart from a few local variations, a remarkably consistent north-north-east wind.

The only other presumed palaeodeserts of the upper Palaeozoic of the United States that have been studied are slightly older than the sandstones of Arizona, being in the uppermost Pennsylvanian and very early Permian. These geologic formations, called the Tensleep, Casper, and Weber sandstone of Wyoming, south-west Wyoming, and Utah respectively, were studied by the authors in the summer of 1956, and it was again found that the direction of the wind was from the north-east (figure 13).

The possibility of tracing the direction of the wind through geological time by means of aeolian sandstones is an interesting project in itself, but it is at present important because it represents one of the few ways in which the determinations of the position of the pole in relation to the land masses through palaeomagnetic measurements can be independently checked. The palaeomagnetic evidence suggests that the western United States and Great Britain were much closer to the equator in Upper Palaeozoic times than they are at present. Figure 15 shows the position of the equator, 20°N, 20°S, and 60°N latitude lines and the poles for late Palaeozoic and early Mesozoic times. It will be seen that both these areas would have been within the wind belt of the northern trade winds if the present width of this belt is typical. It is interesting to see that the evidence from the aeolian sandstones described above supports this prediction. The easterly wind deduced from the Permian of Great Britain and from the late Palaeozoic of the western United States both become north-east winds relative to the position of the equator at that time.

CONCLUSION

There appears, therefore, to be agreement between the wind directions and palaeomagnetic pole positions for North America and Europe in late Palaeozoic and early Mesozoic times. The Botucatu sandstone of Upper Triassic Age of South America is now being studied.

If this promising line of research were extended into other areas of the world, particularly the aeolian sandstones of Africa (Forrest-Bushveld sandstone), the Triassic (perhaps Cretaceous) of Asia, and the possibly aeolian Nubian sandstone of the Middle East, much might be learned about the past patterns of the earth's general atmospheric circulation and climate. If it were possible eventually to read from the rocks the wind directions throughout the geological column in all continents it might be possible to determine whether the trade wind belts have varied in their latitudinal extent through the earth's history. As their extent depends on both the general climatic state of the earth and on its rotation, this would be a very important piece of geophysical evidence, for it is thought that the rotation of the earth has gradually slowed and that a thousand million years ago the length of the day was probably one sixth of the present length. Thus an indirect method of determining the speed of the Earth's rotation throughout geological time would be of great interest.

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The planetarium

H. C. KING

For over two thousand years attempts have been made to illustrate by models or other devices various astronomical phenomena, such as the rising and setting of the celestial bodies, the sequence of day and night, eclipses of the Sun and Moon, and the motions of the planets. This article describes such models, from the early star globes, armillary spheres, and orreries to the modern projection planetarium, which embodies features from all three types.

The idea that the Earth is not a flat disk but a globe placed at the centre of the spherical vault of the heavens appears to have originated in the sixth and fifth centuries B.C. in ancient Greece, where men like Pythagoras and Plato fostered geometry and favoured a geometrical approach to natural phenomena. The sphere, they argued, is the most perfect of all geometrical forms; hence the Earth, no less than the vault of heaven, has a spherical shape. On this basis it became natural to represent the stars on globes, and this was done long before the construction of the first terrestrial globe. Men became familiar with the stars and grouped them in patterns to form constellations many centuries before they could map even the Old World with reasonable accuracy. On the one hand the nightly wheeling of the heavens brought the stars to recurrent appearance, the circumpolar stars in particular lending themselves most favourably to the idea that the stars are fixed like luminous studs to the surface of a rotating celestial sphere. On the other hand, the general acceptance of the idea of a spherical Earth and knowledge of the general distribution and shapes of its land masses had to await the great voyages of discovery of the fifteenth and sixteenth centuries.

One of the earliest star globes appears to have been that which the astronomer Eudoxus of Cnidos either made himself or brought out of Egypt about 370 B.C. A century later the Cilician poet Aratus composed his *Phaenomena*, a poem generally considered to be based on a description of the constellations according to Eudoxus. The earliest extant celestial globe (figure 1) also appears to have had some connection with Eudoxus, for the arrangement of the forty-two constellations sculptured in relief upon its surface suggests that it was probably constructed around 300 B.C. This marble globe, 26 inches in diameter, is supported on the broad shoulders of a statue of kneeling Atlas some six feet high. The entire sculpture is preserved in the National Museum of Naples and is known as the *Atlante Farnesiano*.

According to Cicero [1], C. Sulpicius Gallus, 'a very learned man', told him that Eudoxus adorned his celestial globe 'with the fixed stars of heaven, and with every ornament and embellishment'. Gallus also mentioned a mechanical model of the heavens which Marcellus had carried off from Syracuse in 212 B.C. as part of the spoils of war. It was made by Archimedes, who lost his life when the city was sacked, and the Romans so greatly admired the model heavens or planetarium that Marcellus placed it in the Temple of Virtus. Gallus described the planetarium as a kind of globe in which revolved models of the Sun, Moon, and the five naked-eye planets (then known as the seven wandering stars or planets), each model going through its 'unequal and varied movements' during 'one revolution of the machine'.

In all probability the planetarium of Archimedes was a spherical astrolabe or armillary sphere. In its most simple form the armillary sphere appears to have been used by Eratosthenes, Hipparchus, and other astronomers at Alexandria for the measurement of the positions of the Sun, Moon, and stars. It usually consisted of a group of three or more concentric and intersecting rings which were either mounted on a firm stand or suspended by cords from a ceiling. These rings represented in turn the horizon, meridian, celestial equator, and ecliptic, while an additional movable ring furnished with sights enabled an observer to measure the angular distance of the celestial object from any one of the reference circles. In the hands of the Muslims these armillae became most elaborate, and were used in western Europe for the teaching of astronomy until well into the eighteenth century. One development of the device was to fix a model Earth at the centre of the system of rings so that the instrument could be used to

illustrate the geometry of the Ptolemaic, or Earth-centred, conception of the universe (figure 2). Another development was the flat or planispheric astrolabe, an instrument greatly appreciated and perfected by the Muslims, and one used as an aid to navigation up to the end of the eighteenth century.

The first departure from the idea of a star globe as a sphere having stars and constellation figures marked on its outer surface was made by Adam Oelschläger, or Olearius, court mathematician and librarian to Duke Frederick III of Holstein-Gottorp. Under his superintendence, during the years 1654–64, Andreas Busch of Limberg made a hollow copper sphere about 11 feet in diameter and some 3½ tons in weight (figure 3). Through the sphere passed a solid metal axis supported at each end and inclined at 54½° to the horizon, this angle being the latitude of Gottorp. The outer surface of the sphere showed a map of the known world, and a wide horizontal circle enabled visitors to walk round the globe and examine the map in detail. In the southern part of the globe a small door gave admittance to the interior, which was illuminated by two small oil lamps [2]. Inside, the circular platform suspended from the axis held as many as ten spectators, and from this floor the operator slowly rotated the globe by turning the handle of an Archimedean screw. With the globe in motion a succession of gilded stars and constellation figures appeared to rise and set relative to an artificial horizon. The monthly change in the appearance of the night sky, the diurnal motion of the Sun, and the Sun's apparent motion along the ecliptic were also seen, the sun being represented by a glass sphere which could be given its own motion along the ring of the ecliptic. In 1715 the globe was sent as a present to Czar Peter the Great, who in turn presented it to the St Petersburg Academy of Sciences. According to a recent report it is now preserved in the Zoological Museum, Leningrad.

The next recorded celestial globe of this type was made by Erhard Weigel. In 1654 Weigel became professor of mathematics in the University of Jena and gave much thought to mechanical devices for popularizing astronomy. One of his star globes is now in the Museum of the Franklin Institute, Philadelphia. It is approximately 18 inches in diameter and has an unusual set of constellations, for Weigel changed many of the classical figures to represent the coats of arms of the ruling European families at that time. The stars are formed by little holes punched in the globe, and to see them in their constellations the observer looks into the globe's interior through a large hole.

The largest hollow celestial globe was that designed by Roger Long, Lowndes's Professor of Astronomy at Cambridge, and completed in 1758. Long arranged for the sphere, 18 feet in diameter and suitably inclined for the latitude of Cambridge, to be set up at Pembroke College. It could be rotated by a winch and rackwork, and the stars, as in Weigel's sphere, were represented by holes of various sizes pierced in the metal. As many as thirty visitors could stand inside and watch the rising and setting of the stars relative to an artificial horizon. Long hoped that his sphere would do much to popularize astronomy, but in this he was to be bitterly disappointed. Although he set aside £6 a year for maintenance, the sphere gradually fell into a state of disrepair. W. H. Smyth, writing about it in 1844, says that 'many a good man and true has lived and learned in Cambridge, without even being aware of its existence' [3].

Greater success attended the large star globe which W. W. Atwood designed in 1911 for the express purpose of providing instruction in the fundamentals of astronomy at the Chicago Academy of Sciences (figure 4). The globe was fifteen feet in diameter, made of thin galvanized sheet iron, and weighed no more than 500 lb [4]. It was supported at its equator by three wheels and could be turned by a small electric motor, rotating about an axis inclined at 41° 50′ to the horizontal. The stars were formed by numerous holes, all correctly graded in size and carefully positioned. A small electric light which could be moved along the ecliptic represented the Sun. For the Moon Atwood used one of several small disks cut to represent the phases of the Moon and coated with luminous paint. He even catered for the planets, demonstrating their wanderings among the stars by opening a series of apertures, but this arrangement does not appear to have been very successful.

After the sixteenth century the comparative geometrical simplicity of the Copernican system, compared with that of the Ptolemaic system, greatly aided the construction of models of the solar system. Yet while it was a fairly simple matter to devise a mechanism which would drive model planets in circular orbits with uniform motions about a central Sun, to drive them at approximately the correct proportional speeds with only a small number of simple gear-wheels presented considerable difficulty. The problem was

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FIGURE 1 – *Celestial globe of the* Atlante Farnesiano. *A reproduction in the Warburg collection in the Zeiss Planetarium, Hamburg.*

FIGURE 2 (*right*) – *Armillary sphere by Vopel* (1542). *From an exhibit in the Science Museum, London.* (*Crown copyright, Science Museum, London.*)

FIGURE 3 – *The Gottorp terrestrial and celestial globe.*

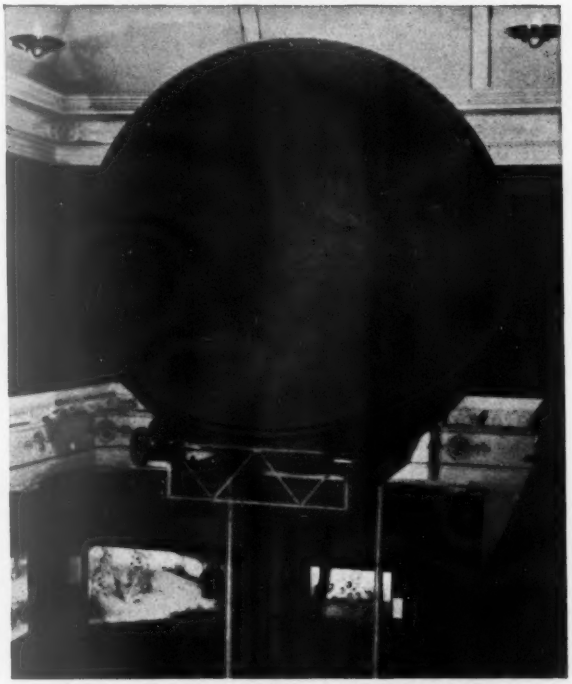
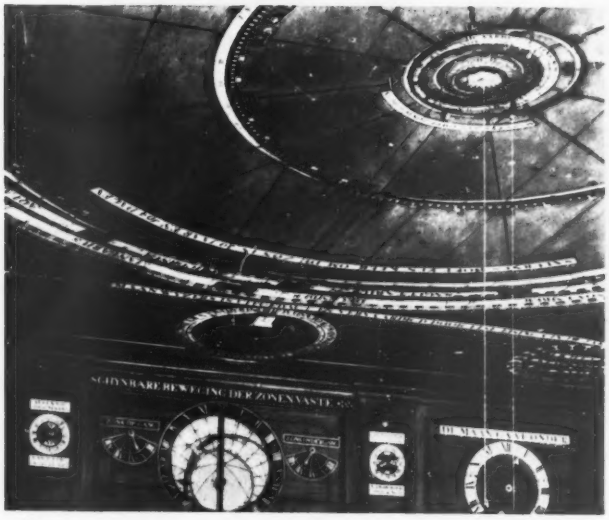


FIGURE 4 – *The Atwood celestial globe in the Museum of the Chicago Academy of Sciences.*

FIGURE 5 – *Huygens's planetarium, showing (left) dial and (right) the movement. (National Museum of the History of Science, Leyden.)*

(a)



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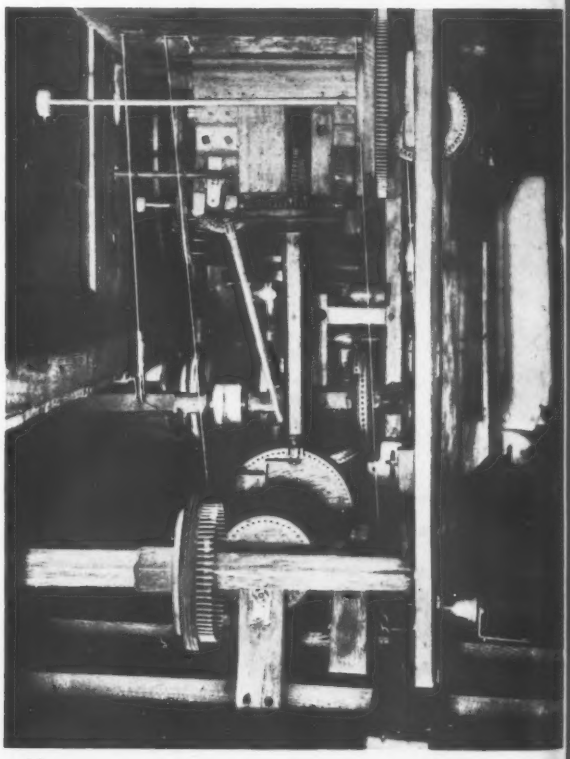

(c)

FIGURE 6 – *Planetarium of Eisinga at Franeker.* (a) *General view;* (b) *detail;* (c) *part of the mechanism.*

FIGURE 7 – *The Tompion and Graham orrery. (Above) general view; (below) movement with two of the stanchions removed.*

FIGURE 8 – *The central face plate of the Rittenhouse orrery in the Princeton University Library.*

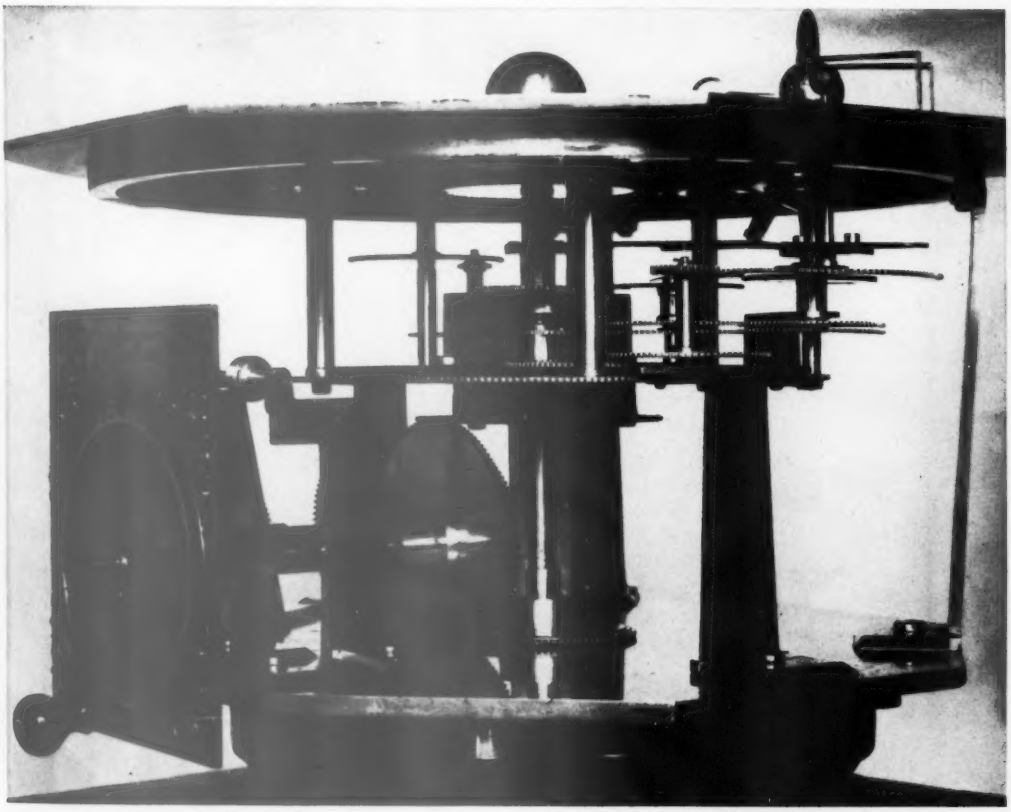

FIGURE 9 – *Orrery by Thomas Wright.* (*Crown copyright, Science Museum, London.*)

FIGURE 10 – *Large orrery by Thomas Wright.* (*Crown copyright, Science Museum, London.*)

FIGURE 11 – *Latest type, or universal, Zeiss planetarium instru*

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successfully solved by the Dutch physicist, Christiaan Huygens. For this purpose he adapted the principle of continued fractions, which enabled him to show, for example, that the Earth globe and Saturn globe of a model solar system would revolve with periods in nearly the correct ratio if the Earth wheel had 7 teeth and the Saturn wheel 206 teeth. On this basis Huygens designed a small planetarium [5], operated by clockwork and gearing, which Johannes van Ceulen made in 1682 at The Hague, and which is now in the National Museum of the History of Science, Leyden (figure 5).

Van Ceulen mounted the mechanism in an octagonal box about 26 inches across and 7 inches deep in whose top copper plate he cut six circular and excentric slots. These slots correspond to the orbits of the six planets up to and including Saturn, and in each one there moves a spindle surmounted by a small model planet. Ideally the model planets should move with variable speeds in elliptical orbits, but Huygens made a clever approximation to this. Although the planets in his planetarium have uniform motions in circular orbits, these orbits are, as mentioned, excentric circles. Their centres are displaced by appropriate amounts from the Sun globe, and the model planets therefore have non-uniform motions as seen from the Sun globe. In this sense their movements represent with fair accuracy the non-uniform motions of the actual planets.

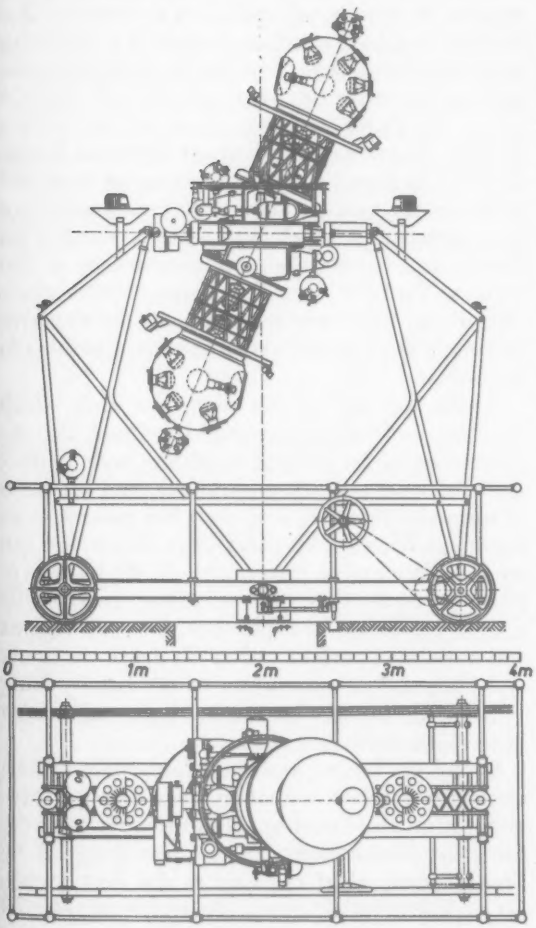

FIGURE 12 – *Diagram of the latest type, or universal, planetarium instrument.*

Huygens was by no means the only one of his time to give attention to the planetarium. In 1679 the Danish astronomer Ole Rømer sent John Flamsteed details of a machine which showed the relative movements of four of Jupiter's satellites. In England, Richard Cumberland, later Bishop of Peterborough, and Stephen Hales of Oxford made simple working models of the Earth–Moon system. George Graham, however, achieved the greatest success by making a full working model of the Earth–Moon system in which the Moon revolved about the Earth, the Earth revolved about the Sun, and both the Earth and the Moon rotated on their axes.

For many years Graham worked with the famous clockmaker Thomas Tompion and eventually became the leading scientific instrument-maker in London. His model of the Earth–Moon–Sun system appears to have been made between 1704 and 1709 and was probably the same in its mechanism and appearance as one by Tompion and Graham now exhibited in the Museum of the History of Science, Oxford [6] (figure 7). According to one account [7], Graham handed his planetarium to John Rowley, another London instrument-maker, to be packed and sent to Prince Eugene of Savoy. Rowley made several copies of the machine, presumably with Graham's consent, and sent one of them to Charles Boyle, fourth Earl of Orrery. Because of this association the device became known as an *orrery*, and the credit for its invention was at first attributed to Rowley. The instrument sent to Charles Boyle is now in the possession of the present Admiral of the Fleet the Earl of Cork and Orrery, and is on loan to the Royal United Service Institution, Whitehall, London. The mechanism is enclosed in a wooden drum or case, 30 inches in diameter and about 9 inches deep. Just above the drum, and supported by twelve gilt pillars, is the ring of the ecliptic. The Earth–Moon system is contained within a

smaller glass-covered drum, which, with the entire top plate, rotates about the central ball of the Sun.

Rowley's orreries were highly valued both as works of art and as scientific curiosities, and several other London instrument-makers soon extended their activities in this direction. Foremost among them in this respect was Thomas Wright (see figure 9), who had his workshop under the sign of 'The Orrery and Globe' in Fleet Street. Wright introduced what later became known as the 'Grand Orrery', an instrument which showed the motions of the Earth, Moon, and the five then-known planets (figure 10). One of these instruments, made in 1733 and installed in the Royal Observatory at Richmond, is said to have cost £1500. It was transferred to King's College, Cambridge, in 1841 and is now on loan to the Science Museum, London. Wright was succeeded in this work by Benjamin Cole and his son at the same address, the Coles being followed by Edward Troughton [8]. Other orreries during this period (1730–1830) were made by the Scottish astronomer James Ferguson and by the London instrument-makers Benjamin Martin, George Adams, Heath and Wing, and W. and S. Jones.

The first American-made orrery was constructed in 1770 by David Rittenhouse, a horologist and astronomer of Norriton, Pennsylvania. Rittenhouse was the first to move the model planets in elliptical orbits and hence to represent the motions of their natural counterparts more truly than ever before. He mounted his model vertically in a handsome glass-fronted cabinet and arranged it in three sections. The central part, about four feet square, contained a working model of the solar system, the planets being actuated by turning a hand-crank. One of the side sections showed the motions of the known satellites of Jupiter and Saturn; the other contained models of the Sun, Moon, and Earth and could be used to demonstrate eclipses, the phases of the Moon, and the Sun's apparent motion along the ecliptic.

In 1771 Rittenhouse sold his orrery for £220 to the College of New Jersey, Princeton, by which time he had moved from Norriton to Philadelphia and finished a second instrument similar to the first. The second orrery was purchased by the College of Philadelphia and is now in the library of Princeton University (figure 8). Troops damaged the first machine during the War of Independence, but it was later repaired by Henry Voigt, assistant to Rittenhouse [9]. It attracted great attention when exhibited at the Chicago World Fair in 1893 and is now at Princeton University.

The largest orrery or Copernican planetarium built before the present century is that made by Eise Eisinga, a woolcomber of Franeker, near Leeuwarden, in West Friesland [10]. He began making it about 1774 and had it in full working order by 1781. The mechanism, weight-driven and regulated by a pendulum, consists largely of cogwheels in the form of oak disks and hoops fitted with metal teeth. It is concealed in the double ceiling of a living room so that the planetarium appears over the head of the observer (figure 6). On looking upwards at the main orrery the observer sees the globes of the planets in their correct relative positions and on a scale for distance of $1 : 10^{12}$. Each planet is carried round by a spindle which moves in its own circular and excentric slot cut in the lower ceiling. The globes revolve in the natural periods of the planets, that for Saturn taking nearly $29\frac{1}{2}$ years to complete its path round the Sun. The Earth globe is accompanied by one for the Moon, which both revolves about the Earth and rotates on its axis once a month. Jupiter is given four satellites and Saturn has five besides its ring, but none of these has independent motion. The ecliptic is represented by a graduated band fixed outside the slot for Saturn and having the same excentricity as that given to the Earth slot. The pointer which moves against the band thereby represents the apparent motion of the Sun and shows the Sun's position in the zodiac.

Above the bed of the room are dials which indicate the Moon's phase and longitude, also the position of its apogee and ascending node. Other dials show the year, day, and hour, and the times of sunrise and sunset, and these are geared to an ingenious moving sky chart from which one can see at a glance what stars are above the horizon at Franeker at the time of observation. In 1825 the nation purchased the planetarium and Eisinga was appointed curator. After his death the house and planetarium were given to the city by King William III; the mechanism has been maintained in working order ever since.

By far the largest and most impressive Copernican planetarium is that in the Deutsches Museum, Munich. Constructed in the early 1920s by the Zeiss Foundation, Jena, it was designed by Franz Meyer, chief engineer at the Zeiss Works [11]. The elliptical iron rails which correspond to the orbits of the six planets are mounted on the ceiling of a cylindrical room about 36 feet in

diameter and just over 9 feet high. The globes which represent the planets are driven along the rails by means of electric motors. When the room is darkened the observer sees the model planets illuminated by light from the central Sun and can watch not only their movements but also those of their satellites, and all at the rate of one year in twelve minutes. In addition, a small platform moves on the floor so that it is always directly beneath the globe of the Earth. To the platform is attached a wide-angle periscope, and when this is directed towards any one planet the observer can watch its apparent geocentric movement relative to the principal stars of the zodiac, the stars being represented by small lights inserted in the wall of the room. Similar but smaller planetaria of this type can also be seen in the Hayden Museum Planetarium, New York, and in the Morehead Planetarium at Chapel Hill, Carolina.

In addition, Oskar von Miller, Director of the Museum, had asked the Zeiss Foundation if it could produce an even more versatile instrument —one which would show the heavens and the motions of the planets from the viewpoint of one stationed on the Earth. To meet this suggestion Walther Bauersfeld of Zeiss turned from ideas which required rods, guides and cranks for moving the model planets to one which involved moving sets of optical projectors. By 1919 he had designed a large fixed hemisphere whose white inner surface acted as a receiving screen for images projected by numerous small projectors placed at the centre. By rotating these projectors, singly or in groups, images of the Sun, Moon, planets, and stars would trace out their individual paths in the planetarium sky [12].

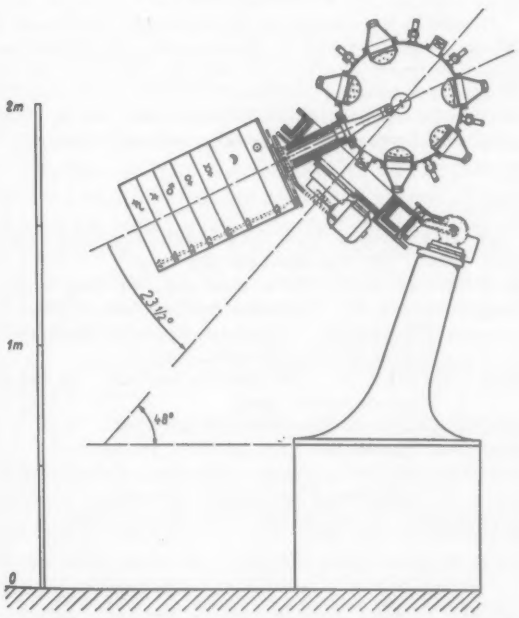

FIGURE 13 – *Diagram of the early type, or fixed-latitude, Zeiss planetarium instrument.*

After five years of intensive work the complex but compact projection instrument became a reality. When set up in a dome on the roof of the Zeiss works its performance exceeded all expectations and public interest was immediate and gratifying. In May 1925 the instrument was installed in the Deutsches Museum, Munich, where it is still in use. A second instrument, similar to the first, was built and placed in Düsseldorf in 1926. Later it was moved to Liegnitz, and then, in 1934, to its present home in the planetarium at The Hague.

The stars formed by each of the first two Zeiss instruments are projected by 31 optical systems distributed over a 20-inch globe and derive their light from a 200-watt bulb fixed at the centre (figure 13). Attached to and rotating with the star globe is a latticework cylinder which contains movable projectors for the Sun, Moon, and five naked-eye planets. These projectors are actuated through suitable gearing by an 'annual' drive which can make the Sun circle the ecliptic in periods which range from a few seconds to several minutes. Once the Sun's image is set in motion in this way, those of the Moon and planets go through their proportionate movements. Spectators see the curious geocentric motions of the planets and can watch them as they wander against the background of stars, advancing and retrogressing as if performing rhythmic arabesques.

The first two Zeiss projectors have the restriction that they show the appearance of the night sky for only one particular latitude. In 1924 W. Villiger of Zeiss effected an important modification by which the starry sky for any latitude may be shown [13]. In this design the projectors are grouped so as to form an array nearly 13 feet long and shaped like a dumb-bell (figures 11, 12). The 'balls' of the dumb-bell are two star globes which between them project about 8900 stars for the northern and southern hemispheres. The projectors for the Sun, Moon, and planets are housed in the cylindrical framework which forms the 'bar' of the dumb-bell. By suitably moving this arrangement it is possible to show the appearance of the heavens as seen from any place on the Earth and at any time past, present, or future.

The seventeen Zeiss planetaria that contain dumb-bell type instruments have almost world-wide distribution. Rome had one in 1928 and Moscow followed suit in 1929. Ten were established in important cities in Germany and Austria between 1925 and 1928, but these have either been destroyed or are no longer in operation. In the United States of America the artificial universe was first shown to the public in May 1930 with the opening of the Adler Planetarium, Chicago. Its great success led others to appear in Philadelphia (1933), Los Angeles and New York (1935), Pittsburgh (1939), and Chapel Hill (1940). Zeiss planetaria are also in operation in Milan, Brussels, Osaka, Paris, Tokyo, and São Paulo. The latest addition to this distinguished list is The London Planetarium, which opened to the general public on 20th March 1958, and which is the first large-scale planetarium in the British Commonwealth [14]. The Zeiss instrument at London is one of a new series produced by the Zeiss works at Oberkochen, Western Germany, who have also made similar instruments for the planetaria at Tokyo, São Paulo, and Hamburg.

Not all the projection planetaria now in operation are built around Zeiss equipment. In 1935 F. D. Korkosz, technician at the Museum of Natural History, Springfield, Mass., completed a star globe projector in which numerous lenses distributed over a globe 5 feet in diameter formed images of the stars on a hemispherical ceiling [15]. Then in 1952 the technical staff of the California Academy of Sciences completed a large Zeiss-type projector which is now installed in the Alexander F. Morrison Planetarium, San Francisco [16].

By far the largest number of projection planetaria, at least in the United States of America, are products of Spitz Laboratories of Yorklyn, Delaware. Spitz instruments range in size from small table models to a large projector which incorporates several Zeiss features and possesses the characteristic dumb-bell shape. In use, however, the Spitz dumb-bell is hung by slender cables from the projection dome, a mode of support which minimizes the occultation of projected images by the supporting framework. The faintest stars are formed by sending light from concentrated zirconium arcs through 3083 pinholes distributed over the two star globes. The 54 brightest stars are produced by individual lens systems, the image of Sirius, the brightest star, being less than $1\frac{1}{4}$ inches in diameter on a 60-foot dome. A large Spitz projector was installed in 1954 in the municipal 'Planetario', Montevideo, Uruguay [17], and other projectors of the same type have just been mounted in planetaria at Flint, Michigan, and at Colorado Springs, Colorado.

So far, therefore, the projection planetarium is unrivalled not just as an educational aid but also as a cultural attraction, and the modern planetarium instrument, so remarkably complex, versatile, and accurate, will long be regarded as a masterpiece of optical engineering.

ACKNOWLEDGMENT

Grateful acknowledgment is due to Dr H. Werner of Messrs Zeiss, Oberkochen, for providing the illustrations shown in figures 1, 3, 4, 8, 11, and 13. Also to P. van der Star of the National Museum of the History of Science, Leyden, for supplying technical information and the photographs of Huygens' planetarium reproduced in figure 5.

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Stellar associations

V. A. AMBARTSUMYAN

Some of the major problems of astronomy concern the ages of the various stars and the processes of star formation, including the question of whether stars are still coming into being. The discovery and study of the stellar associations have provided relevant evidence, and this evidence, together with that obtained by studying other groups, is discussed here.

Astronomers have recently paid considerable attention to the study of age differences between stars. Many of the results have been obtained by the discovery and study of a newly discovered kind of stellar system, the stellar association. Moreover, it can be said that such investigations first made possible a definite assertion that the formation of stars in our stellar system—the Galaxy—is still in progress. By comparing the numbers of stellar associations in various other galaxies of different types, we can draw conclusions concerning the relative amount of star formation in them.

Stellar associations form part of the structure of a galaxy and are akin to the open clusters of stars, groups which have long been known. Some information concerning the ages of the stars and the process of star formation can be obtained from the open clusters. We shall therefore discuss how such information may be obtained.

Observation shows that our Galaxy includes groups of stars in which the star density is higher than in the general star field surrounding them. Each such group as a whole executes a motion round the centre of the Galaxy, similar to that of the Sun and other single or multiple stars. These groups are called stellar clusters. Any star which is a member of such a cluster participates in the general motion of the cluster round the centre of the Galaxy and also executes some motion about the centre of gravity of the cluster. In this respect stellar clusters are analogous to double and multiple stars.

Stellar clusters are of two types. Some clusters contain upwards of tens of thousands of stars. These are the globular clusters. Their structure exhibits a fairly exact, though not always precisely spherical, symmetry. The globular clusters are found both near the galactic plane and at great distances from it.

Other clusters do not possess such a regular form and are much less rich in stars. They contain tens or hundreds, or occasionally thousands, of stars, and are found only near the plane of the Milky Way. Such clusters are called open clusters or galactic clusters. The Pleiades and the Hyades, which are visible to the naked eye, are examples. One of the most beautiful objects to be seen through a small telescope is the double cluster in Perseus, which is at a distance of about 6000 light-years.

The globular and open clusters differ also in the composition and nature of their stellar populations. The open clusters usually contain some blue giants, that is stars having both high luminosities and high temperatures. The globular clusters do not contain blue giants but always contain red giants, stars having low temperatures and very large radii.

Calculation shows that the members of a stellar cluster are retained in it by the forces of their mutual attraction according to the inverse square law. If each cluster were isolated, the processes occurring in it would be entirely determined by these forces. In 1934, however, B. J. Bok called attention to the following point. The stars of the Galaxy in general may pass through or near a cluster with velocities considerably greater than those of the cluster members relative to its centre of gravity. They will then lose some of their energy to the cluster. Consequently the energy of the cluster will increase, and so will its dimensions. After many such passages, the cluster stars will acquire velocities sufficient for them to move apart. The cluster is thus broken up.

It was found that this means of breaking up the cluster is unimportant for globular clusters, whose density is high and whose break-up therefore requires a large amount of externally supplied energy. However, the process indicated by Bok must be very effective as regards many open clusters, whose density is low, so that the gravitational interaction between their members is slight. The break-up of open clusters by this process is calculated to occur in a time of a few thousand

million years, which is comparable with the lifetimes of the stars.

In 1937 the present author showed that there is another break-up mechanism, which in the majority of cases is the more effective. It operates even for those open clusters in which the star density is relatively high. It arises as follows. The motion of the stars in the cluster itself sometimes results in close encounters between them, and the stars which approach each other exchange energies. In some cases one of the stars acquires so much energy that it can overcome the gravitational field and leave the cluster. By the repetition of this process the number of stars in the cluster is reduced, and the cluster gradually becomes an ordinary multiple star.

This sequence of events leads to the break-up of some clusters after a time of the order of a thousand million years, or even less. The fact, therefore, that such clusters are still observed shows that their age cannot exceed one thousand million years. These clusters, therefore, are of an age considerably less than the mean age of the stars in the Galaxy.

It is very important in this connection that the reverse process, the formation of a cluster from stars previously independent, is practically impossible. In other words, the disintegration of clusters in the Galaxy is a one-way process.

If the cluster cannot have been formed from separate stars already existing, it is evident that the process of formation of the cluster was also that by which the stars in it were born. We thus conclude that stars may be formed in groups. It is also clear that different open clusters are of different ages. This means that many clusters were formed when the Galaxy was already in existence.

At the time when these conclusions were drawn it was still not realized that they are of profound importance in the general problem of the origin of the stars. It seemed then that the results obtained referred only to stars in clusters, which form only a small part of the total number of stars in the Galaxy.

At about the same time, however, statistical investigations were being conducted on double stars, which form a very large part of the total number of stars in the Galaxy. These investigations showed that the components of each double star have a common origin. That is, double stars cannot have arisen by the combination of previously independent single stars of the general galactic population.

The deep significance of all these results became clear only much later, soon after the Second World War, when the stellar associations were discovered.

STELLAR ASSOCIATIONS

As we have seen, the open clusters have a star density exceeding that in the surrounding space. Although the star density in the open clusters is much lower than in the globular clusters, they still represent marked concentrations of stars in comparison with the galactic star field around them. The stellar associations are groups of stars in which the star density is lower than that of the background of stars nearby. This does not mean that the stellar associations are rarefactions in the Galaxy. The surrounding stars which are not members of a given association penetrate freely into the volume occupied by it, and so the total star density in that volume is higher, not lower, than in the surrounding space. When we speak of the density of the association, however, we ignore the density due to stars which do not belong to the association and consider only the group of stars which do belong to it. This density is very low, and in this sense the stellar associations are extremely rarefied groups of stars.

The contrast in the density distribution must be reduced by projection on the celestial sphere. If the space density in the region of the association is only a little above that in the surrounding region, then, since we observe only the projection on the celestial sphere, the contrast in density between the association and its surroundings will be entirely negligible. Hence it would be almost impossible to discover associations by examining the apparent distribution of the stars as a whole, whereas ordinary star clusters are revealed on star maps and photographs in this way.

The chief feature of the stellar associations is that the large majority of the stars forming any one association have similar physical characteristics. Thus the members of the associations are mainly in certain definite physical states. This fact made possible the discovery of associations in our Galaxy.

The stellar associations may be assigned to one of the following two classes: the O associations, which consist of large numbers of hot giants, that is, stars of spectral classes O and B and relatively small numbers of other objects; and the T associations, which consist of relatively cool dwarf stars, many of which exhibit irregular variations in brightness.

If we draw a map of the sky which shows only

the blue giants (O and B type stars), the O associations appear immediately as concentrations of stars. This must occur, because the O associations represent very dense regions in the density distribution of the blue giants taken alone.

Similarly, if we insert on the map the known irregular variables of low luminosity (called RW Aurigae type variables), we find that the great majority of them are concentrated in certain regions of the sky. Thus the T associations are very marked concentrations in the density distribution of these variable stars, taken alone.

Since, however, all the blue giants and all the irregular variables of the RW Aurigae type form only a small part of the total number of stars, the associations are almost unnoticeable on maps and direct photographs showing the distribution of all the stars.

Some O associations, nevertheless, which are remote from the galactic plane and relatively near to the Earth will be noticed as groups of stars of high apparent luminosity even against the general background of stars, since in those parts of the sky there are few giant stars in the general background. An example is the dense association in Orion. It includes the bright stars in Orion's Belt and some other bright stars.

The difficulty of directly discovering O associations is due to the fact that numerous other stars of low luminosity but relatively near at hand have about the same apparent brightness as the giants in the associations. The situation is entirely different when we observe other galaxies. All the stars of any other galaxy may be supposed to be at the same distance from us. Hence the bright stars, especially the supergiants and the giants, will stand out from the remainder on account of their high apparent luminosity. The O associations, which contain hot giants, will appear as extensive groups of bright stars. Many such groups are observed, for example, in the Greater Magellanic Cloud. They occur also in the Lesser Magellanic Cloud but are not quite so obvious there, since the luminosity of the brightest stars in associations is somewhat less in the Lesser than in the Greater Magellanic Cloud. O associations are also obvious in the galaxy M33 and the irregular galaxy IC1613.

In a remote galaxy, where the stellar associations cannot be resolved into separate stars, the O associations may appear as concentrations that can be distinguished by their colour, which is bluer than that of the rest of the galaxy.

The O associations are not found in galaxies of the elliptic type, and are relatively rarely found in those of type Sa, where they are not conspicuous. They are very frequently found in late-type spirals and irregular galaxies. These facts are of great interest. The associations are closely related to the spiral structure of the galaxies; in all the spiral galaxies they lie along the arms. It is certain that this relation between the O associations and the spiral arms is of profound significance in cosmogony. The T associations cannot be observed in other galaxies, since they consist of stars of very low luminosity. However, we can obtain some idea of the existence or otherwise of T associations in various types of galaxy from the fact that in most cases they are associated with clouds of cosmic dust. Hence, for example, we may conclude that they do not occur in the elliptic galaxies, since the latter do not contain any notable dark nebulae.

SIZE AND STRUCTURE OF STELLAR ASSOCIATIONS

As has already been mentioned, the mean density of O associations is much less than that of open clusters. Their dimensions, on the other hand, exceed those of open clusters by one or one and a half orders of magnitude. The largest diameters of open clusters lie between 2 and 8 parsecs,[1] while the dimensions of O associations are usually between 30 and 200 parsecs. Still larger associations are observed in other galaxies.

An O association usually contains one or more open clusters. For example, the Orion association contains an open cluster in the neighbourhood of the Trapezium. The association known as Perseus I contains the double cluster h and χ Persei already mentioned, and others. The clusters which are in associations usually contain, among other stars, hot stars of type O or Bo. According to the classification devised at the Byurakan Observatory such clusters are called O clusters. The O associations contain, besides the clusters, other close groups of stars, mainly multiple systems of the type represented by the Trapezium in Orion. Such systems include three stars A, B, C such that all three distances AB, BC, and AC are of the same order of magnitude. Systems of this type are unstable, and must therefore be very young. It should be noticed that most (about 90 per cent) of the known multiple stars do not have this property. Hence the fact that Trapezium-type systems are found mainly in associations

[1] The parsec is a unit of distance used in astronomy, being the distance at which the radius of the Earth's orbit subtends an angle of one second of arc. The parsec is equal to 3·26 light-years, or about 25×10^{12} miles.

is of great importance. Another example is the multiple star σ Orionis in the Orion association. Its principal star is of type O9, while the other four components are of type B. The Trapezium itself is also a member of the Orion association. It is at the centre of the open cluster mentioned above. Another example of a star group found in associations is afforded by the star chains such as Orion's Belt, which consists of O9 and Bo supergiants.

The close groups occurring in associations, clusters, trapezia, and chains, are usually called the nuclei of the association. Thus each O association may have one or more nuclei.

Besides nuclei and individual stars, O associations usually contain gaseous nebulae, the radiation of which is due to hot stars belonging to the association. In some cases the gaseous nebulae are so situated in the association that there can be no doubt of their genetic relation to one of the nuclei. For example, the famous nebula in Orion NGC 1976, which is in the Orion association, is closely related to the Trapezium and the surrounding cluster. Another nebula surrounds the Trapezium-type system σ Orionis. Furthermore, according to Menon, the Orion association contains very large quantities of neutral hydrogen, which emit the 21 cm wavelength radio line. In only one case, that of the association Perseus 1, has no radiating nebula been observed, and radio observations of this show no radiation of neutral hydrogen.

The most striking feature of the T associations is their close connection with the dark nebulae. The members of these associations are embedded in such nebulae. This hampers the investigation of the star distribution in T associations, since the light of many of their members is absorbed by the nebulae. Nevertheless, the data available indicate that T associations contain separate concentrations of stars, similar to the nuclei of the O associations.

As has been said, the T associations contain irregular variables of the RW Aurigae type. Some of these variables have bright-tone spectra. The prototype is the variable T Tauri. Many members of T associations were, in fact, discovered from the bright lines in their spectra, that is because they had spectra of the same type as T Tauri. However, not all RW Aurigae variables are stars of T Tauri type, although all T Tauri stars, apparently, are irregular variables of RW Aurigae type.

The question arises whether the T associations contain dwarfs of constant brightness as well as the RW Aurigae-type variables. Unfortunately this question is difficult to answer, since dwarfs of constant brightness belonging to T associations could not be distinguished from the multitude of similar dwarfs belonging to the general star population. This hampers the study of the structure of T associations. The dimensions of these associations lie between a few parsecs and 100 parsecs. In some cases they are quite dense groups, in others they are rarefied and less dense than the surrounding stars.

THE INSTABILITY OF ASSOCIATIONS

Every stellar system in the Galaxy, including clusters and associations, is subject to tidal forces due to the general gravitational field of the Galaxy. These forces tend to break up the system and to cause its members (in this case, stars) to move in independent orbits round the centre of the Galaxy. If the density of the system is high the gravitational interaction between its members is strong, and the tidal forces are unable to break up the system. It is found that the limiting density below which a system is rapidly broken up by the tidal forces is of the same order of magnitude as the mean density of the galactic star population.

Since the density of the open clusters considerably exceeds that of the galactic population, the tidal forces cannot rapidly break up a cluster. We have seen that the associations, on the other hand, have a density below this critical value, and so they must be broken up by tidal forces almost as soon as they are formed. The time necessary for this process is of the order of 10^7 years. Hence it follows that the age of the stellar associations is of the order of 10^6 years, and in some cases less still.

Since the mean age of the stars in the Galaxy is of the order of thousands of millions of years, and since the associations cannot be formed from previously existing independent stars, we must conclude that the formation of stars in the Galaxy is still in progress.

It can be shown that, if an association is broken up by tidal forces, its final disruption is preceded by the assumption of a very elongated form. Many associations of considerable size, however, are almost spherical. The association Perseus 1 is an example. The only possible explanation of this is that the stars in each such association were ejected from its central regions at the time of their formation, with speeds of the order of tens of kilometres per second. This value is derived theoretically from the sizes of the associations.

In 1952 the Dutch astronomer A. Blaauw, from a study of stellar motions in the association

Perseus II, found that the stars are moving away from the centre of the association at an average speed of about 12 km/sec. Thus the main conclusion of the theory of stellar associations was confirmed. Later the phenomenon of expansion in the O associations Cepheus II, Lacerta, and others was detected by investigating the motions of stars in them.

The proof of this expansion was in turn a direct proof that the members of the associations are young stars, and made possible a more precise determination of their ages. The age of the stars in the association Perseus II, for example, was found to be about 1·3 million years. Ages of a few million years were obtained for other associations.

However, the existence of several nuclei in dense O associations showed that it is not possible to reduce the motion of all the stars in associations to divergence from a single centre. It is natural to suppose that the various nuclei are different centres of star formation, so that the complete picture of stellar motions in the dense associations must be less simple.

The first indications of this were detected by Artyukhina, who showed that in the association Cepheus II there are two centres from which the stars are diverging. The Orion association is more complex. According to Blaauw and Morgan, two stars of early spectral type (AE Aurigae and μ Columbae) are moving very rapidly away from a point near the great nebula in Orion. The investigations of Strand have shown that the cluster around the Trapezium is expanding at about 5 km/sec. This means that the age of this cluster cannot exceed 3×10^6 years, in good agreement with the supposition that Trapezium-type systems are very young. Thus it may be regarded as established that the Orion association contains two expanding groups. It is also certain that this association contains other groups whose motion is different from either of these. For example, there is strong evidence that the three stars of Orion's Belt have a common origin. It has not yet been possible, however, to elucidate the law of motion in this group, on account of the smallness of the relative velocities.

The presence in dense O associations of separate groups formed at different times and expanding independently is an important fact, which must be taken into account in any attempt to reconstruct the origin of the O associations.

THE ORIGIN OF O ASSOCIATIONS

If we follow backwards in time the evolution of an association, we find that each expanding group must at one time have occupied a considerably smaller volume than it does at present. The main question, however, is what the volume of the expanding group was when its stars separated from some primitive body to form isolated objects. It must, of course, be assumed that the luminosity of these objects in the early stages may have been entirely different from that which resulted when each became a star in a more or less steady state.

The fact that systems of the Trapezium type are observed in the associations—systems which are unstable, yet have dimensions of only about 0·1 parsec—indicates that the original volume may have been very small. If we go further, and postulate that the Trapezia, in the early stages of their development, were still denser groups, we reach the conclusion that the pre-stellar body from which the expanding group was formed was of high density. It must also have been very massive, having some hundreds or thousands of times the Sun's mass. Neither observation nor theory indicates that equilibrium configurations of such large masses can exist with dimensions of the order of stellar radii or a few orders of magnitude greater. The present author therefore advanced the hypothesis that the pre-stellar body was 'superdense'. The density of this 'protostar' may have been of the same order as that of an atomic nucleus. It may be that protostars in this state have very low luminosities, and so we have not yet observed them.

It should be emphasized, however, that there is as yet no logical theory of the structure of such protostars such as would explain how the matter in them is subsequently transformed into ordinary stars moving apart at considerable speeds.

A less hypothetical way in which stellar associations might be formed has been suggested by J. H. Oort. According to him, an O-type star in a very massive nebula causes the inner parts of the nebula to become hot and expand. The result is that a compression of the gas occurs in a region at the boundary between the heated inner parts and the outer parts. Owing to the gravitational instability of the resulting condensations, stars are formed at the boundary of the nebula and move away from its centre. It seems to the present author that this theory contradicts the observed fact that Trapezium-type multiple systems, that is, groups of very young stars, are found in the very centres of nebulae.

It should be noticed that the idea that stars are

formed from gaseous nebulae is in accordance with the traditional cosmogonical theories that all celestial objects are formed from nebulae. However, our supposition that groups of stars are formed from superdense protostars necessarily leads to the conclusion that the stars and nebulae were formed simultaneously from the protostar. On this theory, the expansion of the star group and that of the nebula are related phenomena caused by the break-up of the protostar. It should be noted that the idea of the formation of expanding nebulae from dense objects (supernovae, planetary nebulae) is already familiar in astronomy. Thus our viewpoint is to some extent in accord with a tendency known to exist in Nature.

NON-STEADY STARS

As we have seen, the members of T associations are variable stars of the RW Aurigae type. These stars exhibit extremely irregular variations in brightness. It is therefore certain that they are not in a steady state. This is natural, since the members of T associations are young stars.

However, the spectra of some of these objects have interesting features which compel the conclusion that they are emitting not only thermal radiation, i.e. radiation such as we receive from ordinary stars, but also non-thermal radiation, e.g. bremsstrahlung, solar radio waves, and so on. The non-thermal radiation is due to some unknown cause which operates from time to time in the atmospheres of non-steady stars. Whatever the actual mechanism of its emission, it is now clear that it contains energy liberated from powerful sources of some kind in the outermost layers of the star. Thus, in these stars, processes of energy liberation occur not only in the central regions but also in the atmosphere.

The Mexican astronomer Haro has shown that the non-steady stars in T associations include some which 'erupt', their luminosity increasing by several times in a few minutes. In such cases the energy released in the star's atmosphere from unknown sources is emitted during a very short time, and the process of energy release is explosive. How can these phenomena be explained?

Since the non-steady stars discussed here are young objects formed from superdense pre-stellar matter, we may suppose that some of this matter, still unconverted into ordinary stellar matter, remains in them. When the remaining islands of superdense matter in the star reach the outer layers of its atmosphere they are converted into ordinary matter, very large quantities of energy being released.

Thus we reach the idea of quasi-steady condensations of superdense matter (at nuclear density) which spontaneously break up in the outer layers and release energy in discrete quantities, as opposed to the continuous evolution by thermonuclear processes, as in all stars. These releases of energy are then observed as eruptions of non-steady stars.

HERBIG-HARO OBJECTS

We have seen that the O associations include Trapezium-type multiple systems, which are very close groups and, to all appearances, very young objects. The T associations include objects which to some extent correspond to the trapezia. These are the Herbig-Haro objects. They are small nebulae of diameter some 10^4 astronomical units (an astronomical unit is the mean radius of the Earth's orbit) and each contain several star-like condensations. These condensations are arranged similarly to the stars in Trapezium-type multiple systems.

The spectra of the nebulae which contain these condensations are similar to that of the small nebula round T Tauri. However, many of the spectral features which distinguish the latter nebula are more marked in the Herbig-Haro objects. The present author therefore put forward the suggestion that in this case we have star groups which are at the very beginning of their life as T Tauri stars.

This view received strong confirmation from the work of Herbig, who found that in 1954 two new star-like condensations, not previously visible in photographs, appeared in one of the Herbig-Haro objects. Whether we are here direct witnesses of the formation of new stars, or whether this observation indicates the strange and powerful processes occurring in the very early life of a star, is difficult to say. There is no doubt, however, that the study of these processes will lead us yet closer to understanding the way in which the stars are born.

CONCLUSION

We see that the results obtained by astrophysicists in the last ten or fifteen years, and especially the data on stellar associations, have brought nearer the solution of problems pertaining to the origin of the stars.

The most important results are that the process of the formation of stars is still in progress in our

Galaxy and other spiral galaxies, and that stars are formed in groups. It is certain also that the formation of expanding groups in the associations is related to the expansion of gaseous nebulae in them.

The stars formed in associations, however, have as a rule motions such that they do not go far from the galactic plane. The process here considered can therefore explain, at best, the origin of only that part of the stellar population which forms the 'plane sub-system'. By this we mean the galactic disk and the spiral arms.

There is, however, another sub-system, the 'spherical sub-system', or rather several such, whose members may pass far from the galactic plane. One of these spherical sub-systems includes the globular clusters. Another includes the short-period cepheids of the RR Lyrae type—variable stars whose period of variation in brightness is less than a day.

The question arises of the origin of these various objects. According to one theory (Baade, Schwarzschild, Spitzer), all the objects in spherical sub-systems are old, with ages exceeding 3×10^9 years. They were formed from objects in the plane sub-systems which acquired speeds enabling some of them to pass far from the galactic plane.

Another view (Kukarkin), which seems more likely to the present author, is that the great average age of the stars in the spherical sub-systems does not rule out the existence of young objects in them.

The hypothesis that star-group formation may have occurred among these objects also is supported by the presence of globular clusters there. Since the latter are never associated with conspicuous gaseous nebulae, it is evident that those who uphold the traditional view that stars are formed from nebulae must deny that young stars can exist among the members of the spherical sub-systems; but those who think it more probable that stars and nebulae are both formed from a third kind of object, the protostars, will see no reason against the continuing formation of stars even among the population of the spherical sub-systems.

We may hope that the coming years will bring the solution to this problem also. And then we shall be able to say whether or not the strange 'associations' occur even among the members of the spherical sub-systems.

Book reviews

UNDERSTANDING SCIENCE

Harvard Case Histories in Experimental Science, *edited by J. B. Conant. Vol. I, pp. xvi+321; vol. II, pp. vii+325–639. Harvard University Press, Cambridge, Mass.; Oxford University Press, London.* 1958. 80*s. the set.*

Dr Conant, in the course of a long and brilliant career as research chemist, professor, administrator, and diplomat, has had unrivalled opportunities of assessing the layman's lack of an appreciation of the tactics and strategy of science. He finds that even a highly educated and intelligent citizen without research experience will almost always fail to grasp scientific essentials, not because of his ignorance of scientific facts or his unfamiliarity with scientific jargon, but because of his fundamental incomprehension of what science can or cannot accomplish. Yet such a citizen, as a public servant, a lawyer, or a business executive, may find himself required to advise upon how a scientific or technical project can be organized and financed.

There is no easy way out of this difficulty, but Dr Conant feels that the study of 'case histories' in science may lead the uninformed layman to a knowledge of the methods by which science has progressed, and thus equip him with a critical but sympathetic attitude towards experimental investigation in whatever field he has to pass judgment. 'An intimate acquaintance with a relatively few historic cases should assist him in finding his way through the complexities of modern investigation as he listens to those who tell him what is being proposed.'

The cases selected, and very carefully and skilfully treated, are Boyle's experiments in pneumatics, the overthrow of the phlogiston theory, the early development of the concepts of temperature and heat, the atomic-molecular theory, plants and the atmosphere, Pasteur's study of fermentation, Pasteur and Tyndall's study of 'spontaneous generation', and the development of the concept of electric charge. Contributors other than Dr Conant himself are Leonard K. Nash, Duane Roller, and Duane H. D. Roller.

Though one may believe that, for the understanding of science, there is no fully effective substitute for laboratory discipline, these books will certainly go far towards achieving their object.

E. J. HOLMYARD

THEORETICAL ASTROPHYSICS

Theoretical Astrophysics, *edited by V. A. Ambartsumyan. Translated from the Russian by J. B. Sykes. Pp. xii+645. Pergamon Press Ltd, London.* 1958. £6 15*s. net.*

This is an able, valuable, and substantial addition to astrophysical literature. It deals predominantly with the theory required for the more immediate interpretation of the observations. Thus most of the book is concerned with stellar atmospheres and stellar spectra, first of normal stars and then of special stars (planetary nebulae, novae, bright-line stars). There is a considerable section on the outer layers of the Sun, including discussions of the electrodynamics of the Sun's atmosphere and of radio emission from the Sun. There are sections on radiative transfer in planetary atmospheres and on interstellar matter. In keeping with the tenor of the work, there is only a short

section on the internal constitution of the stars.

The physical problems of the subject are discussed very fully but with the use of only the minimum amount of mathematical treatment; uncertainties and difficulties are clearly stated. The book can therefore serve both as a student's textbook and as a guide to research workers. Also, while the authors have tried to describe all existing work within their scope, it will make known to English readers the large amount of recent Russian work. The authors have revised the text for translation and inserted a graceful tribute to British contributions. The translator's skill is superb. W. H. McCREA

INORGANIC REACTION MECHANISMS

Mechanisms of Inorganic Reactions, *by F. Basolo and R. G. Pearson. Pp. xi+426. John Wiley & Sons Inc., New York; Chapman and Hall Ltd, London.* 1958. 94*s. net.*

During recent years a number of excellent books have appeared on the subject of co-ordination compounds, and it might be questioned whether there is the need for another at the present time. This new volume, however, can be sure of a good reception, for it deals with an aspect of co-ordination chemistry which is receiving increasing attention. It is devoted to a discussion of the mechanisms of the reactions of complex compounds. After a helpful introduction the author gives a clear account of the theory of the co-ordinate bond, substitution reactions of octahedral complexes, substitution reactions of square complexes, the stereochemistry of substitution reactions of octahedral complexes, oxidation-reduction reactions, and catalytic effects of co-ordination compounds. He points out that there are three theories which at present are used to explain the structure, stabilities, and general properties of co-ordination compounds. They are the valence bond theory, the molecular orbital theory, and the electrostatic theory, including crystal field corrections. The author concedes that all three can account in a qualitative way for the main features of complexes. However, when it comes to the quantitative calculations he unhesitatingly places the 'electrostatic-plus-crystal-field' theory well in the lead. The authors deserve the thanks of all chemists for making available in such an attractive form an account of important advances in the field of metal complexes. W. WARDLAW

STEROID CHEMISTRY

Chemistry of the Steroids, *by C. W. Shoppee. Pp. vii+314. Butterworths Scientific Publications Ltd, London.* 1958. 50*s. net.*

As a complex problem of structural analysis, and later of synthesis and biosynthesis, the steroids forced the development of new analytic and synthetic methods. As non-aromatic but fairly rigid frameworks of carbon atoms they promoted knowledge of aliphatic substitution and elimination, rotation differences, rotatory dispersion, and absorption spectra. Their importance in animal physiology stimulated invention of new chemical methods to make possible the production of rare but potent steroids from plentiful raw materials.

In Professor Shoppee's book these wider horizons can be glimpsed through the forest of a closely packed text. By using description with a minimum of explanation he largely succeeds in his aim of presenting concisely the state of knowledge of steroid chemistry in 1955–56; an almost total neglect of steroid alkaloids is the principal omission. The work is well arranged, clearly worded, and usually accurate. Formulae are well drawn and the printing is excellent. The short section on biogenesis is, however, spoilt by incorrect formulae for squalene and lanosterol, and double bonds in the side-chains of ergosterol, stigmasterol, etc. are wrongly shown as *cis*.

By the specialist this book will be valued as a classified collection of abstracts. For those who seek to understand the significance of the bare facts, it will make difficult reading.

J. W. CORNFORTH

HUMAN ORIGINS

Traité de Paléontologie. *Vol. VII,* Primates: paléontologie humaine, *by Jean Piveteau. Pp.* 675. *Masson et Cie, Paris.* 1958. *Paper covers, fcs* 12 000 *net; bound, fcs* 12 800 *net.*

The seventh and last volume of this comprehensive French treatise on palaeontology is concerned with the fossil record of the Primates with special reference to the origin of man. Since the author is the distinguished Sorbonne palaeontologist, Dr Piveteau, it goes without saying that it is a thoroughly competent and authoritative work. But it has the additional value that it applies well established palaeontological principles to a particular field of evolution which all too often is apt to be expounded by writers who have had little or no experience in the study and interpretation of fossil material. About one third of the book deals with the lower, non-hominid, Primates; we could have wished that this part had been considerably expanded, in view of the fact that the records of so many important specimens of the early Primates remain scattered in so many different journals, not all of which are readily accessible. The remainder of the book covers what is often broadly called 'human palaeontology.' The author divides the course of hominid evolution into two phases; the first (by far the longest) traces the gradual evolutionary development of the prehuman representatives of the Hominidae, and the second marks the emergence of true 'man'—that is to say, of beings which have the attributes (such as a voluminous brain and the ability to fabricate tools) with which the colloquial terms 'man' and 'human' are ordinarily associated. Of the early fossils which he definitely includes in the Hominidae, perhaps the most interesting are the small-brained creatures whose remains have been found in such abundance in South Africa, the Australopithecinae. The earliest representatives of 'humanity,' in the sense in which Piveteau uses this term, are those of *Pithecanthropus* of Early or Middle Pleistocene date, and from this ancient type to *Homo sapiens* the fossil record provides a fairly closely graded sequence. Without doubt, this book is essential as a standard work of reference for all students of Primate palaeontology. W. E. LE GROS CLARK

DARWINISM TODAY

A Century of Darwin, *edited by S. A. Barnett. Pp. xvi+376. William Heinemann Ltd, London.* 1958. 30*s. net.*

These fifteen essays do not, in general, attempt to trace the course of biological thought in the period since Darwin worked. Most of them set out to explain the present position of some problem, major or minor, which engaged him and still interests us today. The result is a more striking tribute to Darwin than could have been given by any piece of pious hagiography, for his thought appears, over and over again, to be wholly relevant to contemporary studies.

Dr Barnett's distinguished contributors have served him well. All the

essays are clearly written and will give pleasure to professional biologist, student, and serious naturalist alike. I should like to mention especially those by T. Dobzhansky on the species problem, C. M. Yonge on coral reefs, and J. Heslop-Harrison on Darwin as a botanist, as having pleased me most. D. Michie's proclamation of the dawn of a third stage in genetics is, I think, usefully provocative, though R. A. Crowson's iconoclastic attack in dealing with problems of classification seems, to a non-specialist, to misfire. J. Maynard Smith on sexual selection, and W. E. Le Gros Clark on the descent of man are both admirable. There are essays on Darwinism and sociology and on the possible implications of evolution for ethics. D. R. NEWTH

MUCOPOLYSACCHARIDES

Ciba Foundation Symposium on the Chemistry and Biology of Mucopolysaccharides, *edited by G. E. W. Wolstenholme and Maeve O'Connor. Pp. xii+323. J. and A. Churchill Ltd, London.* 1958. 54*s. net.*

Mucopolysaccharides and mucoproteins are substances containing complex macromolecular carbohydrates and amino acids. Their detailed chemistry is as yet ill defined, though their biological importance is profound since they form important constituents of living cells. The book describes a timely discussion by a relatively small group of experts from many countries who were brought together by the Ciba Foundation under the able chairmanship of W. T. J. Morgan.

The general organic chemical techniques applied to problems of structure in the group is reviewed by M. Stacey, the physico-chemical approach is described by reference to hyaluronic acids by A. G. Ogston, while the novel immunochemical method of determining structure is ably outlined by E. A. Kabat. The latter method, involving the specific inhibition of complex immunochemical reactions by means of disaccharides and oligo-saccharides of known structure is already proving particularly valuable in throwing light on the molecular architecture of blood group factors and of the pneumococcus and other bacterial specific polysaccharides.

A number of discussions by Jeanloz, Partridge, Dische, and colleagues on the sulphated amino sugar-containing mucopolysaccharides are described, special attention being paid to the chondroitin sulphate complex in cartilage and to connective tissue constituents. There is a provocative account (Meier) of the pharmacological effects of polysaccharides and an important one (Westphal) on the components of Gram-negative bacteria. Other interesting subjects discussed are the nitrogen-containing saccharides in human milk (Gyorgy), blood group specific substances (Morgan)and the mucopolysaccharides of epithelial mucus (Odin), plasma (Winzler) and urine (Maclagan, Anderson). Perhaps the most important chapters are those describing the sialic (neuraminic) group of compounds and their relationship to influenza virus. Sialic acid was discovered over 20 years ago by Blix in submaxillary mucus and although very labile it was later crystallized by him. Klenk obtained the same substance from the degradation of gangliosides and it is cropping up in free or bound form in many places where tissue material is being examined in health and disease. The experts, Blix, Klenk, Gottschalk, Svennerholm, and others, bring the subject up to date.

The discussions are faithfully described in all sections. They are exciting and stimulating and this book, which is well up to the standard of previous Ciba Foundation books, will need to be read by all biochemists. M. STACEY

PLANT GROWTH

Control of the Plant Environment, *edited by J. P. Hudson. Pp. xvi+240. Butterworths Scientific Publications Ltd, London; Academic Press Inc., New York.* 1957. 42*s. net.*

The symposia held at the School of Agriculture in the University of Nottingham have rapidly become established as a valuable meeting place of biological and agricultural sciences. In this book Professor Hudson has promptly and successfully recorded the proceedings of the symposium which was held at Sutton Bonnington in 1957.

A central theme running through the papers and discussions was the study of the growth and development of plants under controlled environmental conditions. Plant physiologists and all those concerned with the basic problems of plant culture will find much to interest them: it is primarily a book for the specialist.

In the first two parts of the book ten main contributions are reported. Some of them are general reviews, of rather variable quality, of plant growth and development, while others deal more specifically with the influence of environmental factors, such as temperature, light intensity, wind, and soil moisture. More attention is given to climatic rather than edaphic conditions. The later parts of the book deal with installations and equipment which have been developed for controlling environmental conditions for experimental work on plant growth. A great range of equipment is covered, varying from phytotrons to simple growth chambers and cabinets. Although many of the accounts are very brief, they will be of particular interest to experimentalists in a field in which rapid progress is now being made. E. W. YEMM

NINETEENTH-CENTURY CHEMICAL INDUSTRY

The Chemical Industry during the Nineteenth Century, *by L. F. Haber. Pp. x+292. Oxford University Press, London.* 1957. 45*s. net.*

This attractive, original, and objective work, well documented and carrying a useful bibliography, is described as 'a study of the economic aspects of applied chemistry in Europe and North America'. But besides this it discusses the effect of chemical education—sometimes the apparent insufficiency of it—on the growth of the chemical industry, together with labour questions and sociological factors. It thus breaks new ground in a number of ways and is a valuable contribution that will be welcomed by chemists generally, especially perhaps for the light it sheds upon British and Continental interrelations. Despite the wide title, Dr Haber deals mainly with the acid, alkali, bleaching powder, and dyestuffs branches of the chemical industry, and the picture drawn, effective as it is, is not complete. It seems a pity to maintain that chemistry in the nineteenth century had at last ceased to be the 'handmaiden of medicine and metallurgy,' only to leave out both these important aspects and to present it as the handmaiden of the textile industries. It must be admitted, nevertheless, that the manufactures chosen were the most important until well into the twentieth century.

Though the author has made every effort to avoid bias, there are several places where the facts do not seem to be presented quite correctly. Black did welcome Lavoisier's views (page 31). The Institute of Chemistry, founded in 1877, was scarcely a specialist body

(page 78) but a professional and qualifying organization—even more strictly so than the *Verein deutscher Chemiker*. It contained a strong contingent of analytical and consulting chemists, but Professor Edward Frankland, its first president, was hardly a typical British consultant (page 191); Cross and Bevan, who patented the viscose process, were perhaps more representative. Though coal-tar figures prominently as the basic raw material of dyestuffs, the increased output of benzole during the 1880s does not seem adequately explained, nor could reference be found to W. Young's patent of 1875, for the recovery of benzole from gas by oil washing, though one of Brunck's is mentioned, to which the date 1887 is given (page 86).

Despite occasioning such misgivings, however, it remains true that this is such an interesting and instructive work, and so packed with information, that it should be made available to every student of chemistry. More mature chemists will, or should, read it as a matter of course. Economists and sociologists should not overlook it.

F. W. GIBBS

HISTORY OF MATHEMATICS

A History of Mathematics, *by J. F. Scott. Pp. x+266. Taylor and Francis Ltd, London.* 1958. 63*s. net.*

This is a brief and stimulating account of the development of mathematics from the Rhind papyrus to the *Disquisitiones arithmeticae* of Gauss. Its especial value is the careful reproduction of the exact words and symbols employed by the great masters in some of their most characteristic work, and a generous appreciation of the difficulties under which they laboured. Strict chronological order is rightly subordinated to the more natural and logical scheme of following the development of ideas. The book is illustrated by five magnificent photographs of certain classical mathematical writings and provides brief biographies of the more important practitioners of this art. G. TEMPLE

GALILEO

The Crime of Galileo, *by Giorgio de Santillana. Pp. xvi+339. William Heinemann Ltd, London.* 1958. 30*s. net.*

In 1613 Galileo wrote to Father Benedetto Castelli a letter defending against clerical criticism the Copernican hypothesis of a moving earth, including citation of the Holy Scriptures. This letter caused some commotion, especially among the less erudite and less exalted of the Church, but it was evident that the Church was not anxious to proceed vigorously against the writer if he, on his part, did not press for a ruling. Galileo, however, like certain other great men, was sardonically brilliant and powerfully controversial, rather than tactful, little able to suffer gladly fools even in high places, with the result, then as now, inevitable. How he ultimately provoked a decision which it was in his interest to avoid is, in outline, a familiar story.

In the book before us the learned author enters in great detail into the complicated chain of events, the personalities and the intrigues that led up to the trial before the Inquisition in 1633 and describes the trial itself and its aftermath. In the course of this he gives careful studies of various figures concerned, including especially Cardinal Bellarmine and Pope Urban VIII. The work evinces a close acquaintance with the historical background and the general Italian scene of the time. It sometimes happens that the account of tedious intrigue becomes itself a little tedious, but this is inevitable.

The mixture of classical Italy and modern America exemplified by the translation 'But what a pity that Mr Galileo has gotten involved in these entertainment tricks' is probably intentional, for one object of the author is to show how similar the modern United States and Galileo's Italy were in the treatment of science by the State Services and the Church respectively. In fact, he considers Oppenheimer to be in some ways a modern Galileo.

It is to be regretted that in a work of scholarship of this nature so little trouble has been taken with the references. Passages from contemporary works are introduced without any indication of origin, and books in Italian and Latin are quoted by English titles without even an indication as to what was the original language; the *Sidereus Nuncius* is cited indifferently as the 'Messenger from the Stars', the 'Starry Messenger', and the 'Sidereal Messenger'. It is strange, too, that there should be no bibliography whatever and that in the index a name like Copernicus should be followed by some forty page numbers without any indication as to what is concerned. Altogether, the serious scholar is not much helped should he wish to pursue any particular question. E. N. DA C. ANDRADE

THE HISTORY OF MECHANICS

A History of Mechanics, *by René Dugas, translated from the French by J. R. Maddox. Pp.* 671. *Routledge and Kegan Paul Ltd, London.* 1957. 100*s. net.*

The task that the author has undertaken is indeed a formidable one, that of producing a history of mechanics, in all its aspects, covering the subject from the speculations of Aristotle to the achievements of de Broglie and Dirac, considering with like care the work of Jerome Cardan and of Arthur Compton, of Jean Buridan and of Niels Bohr. The scope may, perhaps, be best indicated by citing the titles of the five parts of which the work consists: 'The Origins', taking matters up to the times of Tartaglia and of Kepler's laws; 'The Formation of Classical Mechanics', including Stevinus, Huygens, and Newton; 'The Development of the Principles of Classical Mechanics in the XVIIIth Century', dealing with discovery from Jean Bernouilli to Lagrange; 'The Evolution of Classical Mechanics after Lagrange', considering developments from Laplace to Helmholtz, with Henri Poincaré's penetrating criticisms; and 'The Principles of the Modern Physical Theories of Mechanics', covering matters from the coming of relativity to the recent development of quantum mechanics by Heisenberg and Schrödinger.

René Dugas possesses the width of mind and sympathy, the depth of scholarship, and the precise knowledge necessary for such an undertaking. His book has been widely welcomed in its original French, and its English form is sure of an honoured and much visited place on the shelves of those students of scientific history to whom this language is more familiar. It is a pity that the translator has preserved many names of persons and places in French forms not used in English and in other matters has retained French conventions which, no doubt, are as well justified as ours but are unfamiliar.

Criticisms can, of course, be made in such minor matters as the neglect of Newton's foundation of the theory of wave motion, but it would be ungracious to quibble about small points when the general standard is so high and the task so demanding. Just tribute is paid throughout the book to the work of Duhem and it is to be regretted the space prohibits the reproduction here of his striking prophecy, made in 1903, of the coming scope and importance of the quantum theory. Those interested will find it on page 457.

E. N. DA C. ANDRADE

Short notices of books

(These notices are descriptive rather than critical and are designed to give a general indication of the nature and scope of the books.)

An Introduction to Statistical Mechanics, *by J. S. R. Chisholm and A. H. de Borde. Pp. ix+160. Pergamon Press, London.* 1958. 35*s.* net.

The authors of this book use an adaptation of the Darwin-Fowler method to introduce the student without a full knowledge of the complex integral calculus to equilibrium statistical mechanics. They pay special attention to the Third Law of Thermodynamics and endeavour throughout to maintain a balance between theory and application.

Advances in Genetics, *Vol. IX, edited by M. Demerec. Pp. viii+294. Academic Press, Inc., New York; Academic Books Ltd, London,* 1958. $8.80 *net.*

This book contains six medium-length reviews of the following subjects: the population genetics of *Drosophila robusta* by H. L. Carson, the genetics of Basidiomycetes by H. P. Papazian, genetic analysis based on mitotic recombination by G. Pontecorvo and E. Käffer, an 8-chromosome map of *Aspergillus nidulans* by E. Käffer, the inviability, weakness, and sterility of interspecific hybrids by G. L. Stebbins, and the mechanism of sex determination in dioecious flowering plants by M. Westergaard. The papers are intended for research workers in these and related fields, and include lists of references.

Ion Exchange Resins (*second edition*), *by R. Kunin. Pp. xiii+466. John Wiley and Sons Inc., New York; Chapman and Hall Ltd, London.* 1958. 88*s. net.*

The increase in the utilization of ion exchange resins necessitated extensive revision of the first edition of this book, published eight years ago. The sections on permselective membranes, hydrometallurgy, sugar refining, and specific exchange resins have been enlarged to separate chapters, and new material on liquid ion exchangers, catalysis, stability, and the uses of ion exchange resins has also been added. This book is intended, as was the previous edition, to provide an overall survey of the field for those who are working in only a part of it.

Actions chimiques et biologiques des radiations. *Part III. Edited by M. Haïssinsky. Pp. 222. Masson et Cie, Paris.* 1958. *Paper covers, fcs.* 4000*; bound, fcs.* 4800 *net.*

This book is divided into three parts. The first, by M. Burton, deals with radiolysis of organic liquids. The second part, by A. Chapiro and M. Magat, with polymerizations brought about by radiation, and the third, by A. Charlesby, with the effect of high-energy radiation on polymers. The book is directed at the non-specialist as well as the radiochemist and radiobiologist.

The Effects of Atomic Radiation on Oceanography and Fisheries. *Pp. ix+137. Published by the National Academy of Sciences, National Research Council, Washington, D.C.* 1957. $2 *net.*

This is one of a series of studies of the biological effects of atomic radiation that was started in 1955; first reports were issued as the Biological Effects of Atomic Radiation—Summary Reports, and this is an account of the continuation of the work of one of the committees. The thirteen chapters cover in detail the various aspects of the use of the ocean as a receptacle for artificially radioactive materials as well as the use of tracer techniques, used both for the measurement of physical and chemical processes in the sea and atmosphere, and for large-scale biological experiments. There are lists of references appended to the chapters.

Extra Pharmacopoeia, *Vol. I. 24th Edition. Pp. xxx+1695. The Pharmaceutical Press, London.* 1958. 65*s. net.*

This book has been completely revised since the last edition. One alteration is that of following the lead of the British Pharmacopoeia and the British Pharmacopoeia Codex in using English instead of Latin for the main titles of drugs. The contents include a list of changes in the British Pharmacopoeia, a list of drugs, their doses and uses, and special sections on antibiotics, immunological products, and radioactive isotopes. There is a therapeutic index as well as a special index.

Aliphatic Fluorine Compounds, *by A. M. Lovelace, W. Postelnek, and D. A. Rausch. Pp. x+370. Reinhold Publishing Corporation, New York; Chapman and Hall Ltd, London.* 1958. 100*s. net.*

The preparation and properties of all reported non-aromatic organic fluorine compounds are covered by this book. It does not give the practical details for the preparations mentioned, but provides the references; it includes 60 tables giving the physical properties of some 4500 organic fluorine compounds.

La chromatographie, *by L. Savidan. Pp. vii+109. Dunod, Paris,* 1958. *Fcs.* 680 *net.*

The theory of chromatography is dealt with in the beginning of this small book, which goes on to describe the methods, apparatus, and applications of this new technique. It is not intended to replace the standard works of reference, but is designed for chemistry students and those chemists, biologists, and other scientists who want a clear and concise introduction to chromatography.

Atomic Energy and Agriculture, *by C. L. Comar. Pp. x+450. American Association for the Advancement of Science, Washington, D.C.; Bailey Bros. and Swinfen Ltd, London.* 1957. 86*s. net.*

This is the account of a symposium presented at Atlanta in December 1955. Twenty-two papers are published, and the subjects reviewed include the uses of radioisotopes in agricultural research, radiation processing of foods, and the solubility and plant utilization of micronutrients. The papers are accompanied by extensive bibliographies.

Précis de pétrographie, *by J. Jung. Pp.* 314. *Masson et Cie., Paris.* 1958. *Paper covers, fcs.* 3600*; bound, fcs.* 4600 *net.*

This is an introductory text book for students on the use of the polarizing microscope in petrography. It aims at showing how this instrument can give information on the mineralogical constitution of rocks, and on their history and inter-relationships. There are a large number of illustrations in line and half-tone and an extensive index.

Notes on contributors

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Received his A.B. degree in chemistry from the University of California at Los Angeles in 1934 and his Ph.D. in chemistry from the University of California, Berkeley, in 1937. He is co-discoverer of nine transuranium elements, including plutonium, and of the fissionable isotopes Pu^{239} and U^{233}. He is the originator of the actinide concept for the placing of the heaviest elements in the periodic table of the elements. He, together with E. M. McMillan, was awarded the Nobel Prize in Chemistry for 1951 in recognition of his work with the transuranium elements. On leave of absence from the University of California to the Metallurgical Laboratory of the University of Chicago from 1942 to 1946, he was primarily responsible for the laboratory development of the chemical procedure which was used for the separation of plutonium at Clinton, Tennessee, and Hanford, Washington, during the war. He served as a member of the General Advisory Committee to the Atomic Energy Commission from 1946 to 1950. He became Professor of Chemistry in the Department of Chemistry in 1945 and Associate Director of the Radiation Laboratory at the University of California at Berkeley in 1954. From 1945 to 1958 he served as Director of Nuclear Chemical Research at the Radiation Laboratory. He is at present Chancellor of the University of California at Berkeley.

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Was born in London in December 1887 and was educated at St Dunstan's College, the Universities of London, Manchester, and Heidelberg, and the Cavendish Laboratory, Cambridge. He served as an artillery officer in France in the war of 1914–18, and afterwards was for some years professor at the Artillery College (later the Royal Military College of Science). In 1928 he was appointed Quain professor of physics in the University of London. At University College he established a flourishing school of physics, known for fundamental work on the mechanical properties of the solid and liquid state. In January 1950 he was appointed Director in the Royal Institution of Great Britain and Director of the Davy Faraday Research Laboratory, but in 1952 resigned, like his predecessor. He maintains close connection with colleagues overseas, and is *Membre Correspondant de l'Académie des Sciences, Institut de France.* He is known for the clarity of his exposition of science, both in writing and by lectures.

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Was born in 1908. He is President of the Armenian Academy of Sciences and a member of the Academy of Sciences of the U.S.S.R. In 1945 he became director of the Abastumanskaya Observatory near Erivan in Armenia, and in 1946 and 1950 respectively he received Stalin prizes for his work on the absorption of light in cloudy atmospheres and on stellar associations. In 1948 he became a vice-president of the International Astronomical Union. His many published works deal with the properties of nebulae, the dynamics of stellar systems, and the structure of stars.